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HIGH SCHOOL
PHYSICAL GEOGRAPHY

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HIGH SCHOOL PHYSICAL GEOGRAPHY

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PREFACE

In order to fit this work for use in Canadian schools, some changes have been made in the order of topics and in the subject-matter. For this revision the authors are largely indebted to Professor A. P. Coleman of the University of Toronto, who has given the volume the benefit of his intimate knowledge of the geography and geology of the Dominion, substituting in every chapter pertinent examples and discussions in place of material which would have special value only in the United States. New chapters have been added, dealing with rocks, with the physical history of Canada, and with matters of elementary astronomy. For the chapters dealing with astronomy Professor C. A. Chant of the University of Toronto is responsible. The study of rocks is introduced before the processes are taken up in detail, and the account of the earth's relations to the sun is transferred to a point near the end of the book. Suitable substitutions have been made in the maps and half-tone illustrations. Notwithstanding these changes, the volume distinctly keeps its identity, and is issued in its new dress in the hope that it may be useful in geographic instruction in the High Schools, Collegiate Institutes and Academies of Canada.

The authors are specially indebted to Professors Coleman and Chant, and to the Canadian Pacific Railway Company for many of the illustrations used in this edition.

August, 1909.

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PHYSICAL GEOGRAPHY

CHAPTER I

CHANGES OF THE EARTH'S SURFACE

Land and water. — The student already knows from his study of elementary geography the relative areas of water and land, and knows also much of the continents and their arrangement. It is almost certain that there is open sea, save for ice, about the north pole, and land

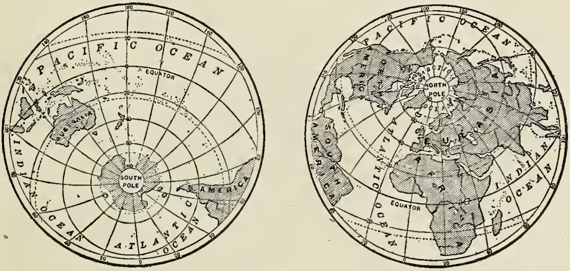


Fig. 1.

Water hemisphere. Land hemisphere.

sheeted with ice about the south pole. The great lands are wide at the north, where they almost encircle the world. The great seas are continuous towards the south, and reach northwards in the several oceans. We may regard the seas as one spherical sheet of water, interrupted by lands large and small. The great lands narrow, or are invaded by extensions of the sea, near the equatorial belt, so that the cutting of slender necks at Suez and in Panama

completes a water passage around the globe. Low coral islands and high volcanic islands are numerous in the seas, and there is no point on the globe which is more than a few hundred miles from some land. We can also make an instructive division of the earth into a land hemisphere and a water hemisphere (Fig. 1).

These facts will help us towards imagining the earth's surface as a whole, but it is much more important to know how the sea and land affect each other. The mud which stains the waters of a brook after a rain will go to the river and then to the sea, and on its bottom, some of it

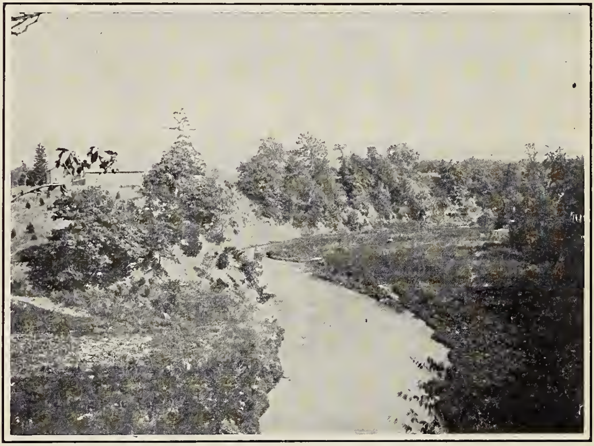


FIG. 2. — The brook is a carrier. As the rock of the high bank crumbles, fragments fall into the water and are swept away. The brook is also a digger. In time of flood, its strong current, thrown against the bank at the bend, tears out stones and earth.

hundreds of miles from shore, will come to rest. Thus the material of the land is constantly cast into the sea.

The sun beats on the surface of the sea and lifts its waters as invisible vapour. This is blown over the land, condensed

to rain or snow, and falls, creating all rivers, watering the fields, and making life on land possible. So far as we can see, there could not be a living world without the ocean. In the chapters on the land and on the ocean we shall learn of many other links that bind the two and make our planet one world indeed. There is no part so distant that it does not help to make us what we are.

Streams of water. — If we study a brook, we find that every time it rises in flood its course is changed. Here an overhanging bank is washed away, making a tree fall; there a shelving shore is built higher by a deposit of mud or sand. Here a gravelly bar grows longer or shorter; there a swimming pool is made deeper or shallower. Similar changes, on a larger scale, take place along the track of the Mississippi, the Danube, or the Amazon. Valleys are dug out, and the waste of mountains and hills is brought to rest in the valleys or swept out to sea.

Rivers of ice, or glaciers. — Among the peaks of lofty mountains are other streams made of ice, not more marvellous, perhaps, than streams of water, but exciting our wonder because far away and unfamiliar. Glaciers are fed by the wintry snows of the cold heights, and creep downwards until melted by the warmer air of the lowlands. They also are carriers, plucking pebbles and boulders and fine earth from their channels, and dropping them in the valleys below. Many centuries ago, before the records of history began, immense glaciers, or ice-sheets, overspread much of Canada and encroached on the United States. The time of this ice invasion is called the *Ice Age*, or the *Glacial Epoch*, and the geography of many lands then underwent important changes.

The outflow of lava in volcanoes. — Not less strange and wonderful to us is the flow of lava, pouring out of the earth like molten iron from a furnace, hardening as it cools, and pouring and hardening again and again,

till a hill or mountain is built up; or the bursting of other lava into ash-like fragments which rain on the surrounding lands till fields and meadows, and even forests and cities, are buried and destroyed. The volcano tells not only of great heat below the outer layers of the crust, but of forces so enormous that the crust itself is rent in giving passage to the pent-up liquid.

Up and down movements of the land. — Many students may find near their homes rocks which contain shells that grew in the sea. They were enclosed in muds of the sea-bottom, the muds were hardened into the rocks, and rocks and shells are now perhaps hundreds, or even thousands, of feet above the water. This means that old sea-bottoms have come up out of the water and now form land.

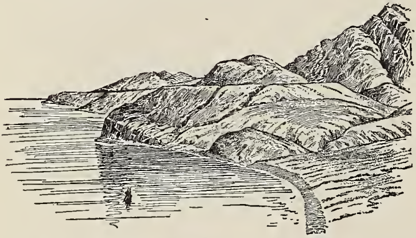


Fig. 3. — An uplifted sea-margin. The beating of waves washes away rock and earth at the shore, especially on bold capes, making cliffs and shelves. When the land is lifted higher the same thing is done along the new shore-line.

Deposits with sea-shells and with fish which now live in the Gulf of St. Lawrence, and even bones of whales, have been found near Smith Falls, Ottawa, and at other points in eastern Ontario. On Montreal Mountain there are gravel beaches with plentiful marine shells 560 feet above the sea; and similar old seashores are found all along the lower St. Lawrence, on the coast of Labrador, and around Hudson Bay. Similar old sea-margins, cut against the slopes of the land, are found on the borders of Alaska, Scotland, and Norway. Villages and landing-places have been left inland since men began to record

modern history. In other places sinking has been going on. On the isthmus connecting Nova Scotia and New Brunswick, excavations have shown a bed of peat sixty feet below tide level, proof of a depression to that extent, since peat cannot form under salt water. Such movements go on very slowly — so slowly that they cannot be felt or seen, but the result may be measured after a period of time.

The atmosphere. — Here is land and there is sea, but over all is the air, invisible, but keenly felt, forming a blanket covering the continents and the oceans. It is indeed a blanket, for without its protection, heat would fly off into space and the surface of the earth would be always frozen. It is never long still, and in its ebb and flow, its creep and rush over the earth, it is the great carrier of clouds and of heat. It is in some way breathed by all living creatures, even by the lowest plants and by animals in the deepest seas, and thus, in many ways, is necessary to life.

Living things. — The early settlers found Quebec and Ontario covered with dense forests; while in Manitoba grew the grasses and flowers of the prairies. In the western mountains trees and meadows and gardens of Alpine flowers predominate over rocks and snows. And so, the world over, the carpet of vegetation colours every picture. Insects and birds fill the lower air, beasts tread the ground, and worms and burrowing creatures occupy the soil. All lakes of fresh water teem with fish, and the ocean has infinitely more life than all the lands together. We do not, of course, forget that land life is much of it of a higher sort; but we find the best teaching of geography in seeing how the land and sea, and the sea of air above them, have helped to make all living creatures what they are. An oyster cannot live upon the land nor an oak in the sea. A palm would die in Greenland,

and a reindeer would pine in a Southern home. Each has come to its estate through the long history of its ancestors, living in conditions of moisture or dryness, heat or cold, and influenced by them.

Continuous change. — It is important to obtain a clear understanding of the fact that the face of the earth is always changing. The mud and sand of the flooded brook were washed by rain from field and hillside, and their removal changed the form of the surface. When their journey ends and they again come to rest under the sea, they change the form of the sea-bottom. The work of each storm may be so small that we can hardly detect it; but time is long, and all the storms of thousands of centuries can even remove hills, or hollow out valleys, or make shoals where once the ocean was deep. A glacier creeps along so slowly that we must make careful measurements to be sure that it moves at all, but by grinding away for ages it makes great changes in the form of its bed and builds high hills of stony waste at its end. The work of the volcano is more conspicuous, because it heaps up a hill or blasts out a hollow by a single effort. Where the land is rising, bays are becoming gradually shoal and narrow, capes are extending and islands are broadening, straits are giving place to isthmuses, and the whole coast is gaining new outlines.

We know, too, that such changes have been in progress for an immense period in the past. By means of them the forms of land and sea, the plains and valleys, hills and mountains, have been made and remade, until every feature is the result of change. There was a time when men thought of the earth as unchanging, but the geographer no longer speaks of the "everlasting hills." He believes each shape of the surface to have been produced through some series of changes, and in seeking to learn the history of its origin finds never-failing interest.

A growing world is a living world, and to study geography well is to look upon the noblest of panoramas.

Geography. — If we wish to know the other planets in our solar system, or the arrangement of the fixed stars, we study *astronomy.* If we would learn the laws and uses of electricity, we turn to *physics.* If we desire knowledge of the ancient history of our earth, of the growth of its land and of the animals and plants of long ago, we study *geology.* Should our object be to understand animals or plants in a thorough way, *zoölogy* or *botany* would be our theme. But our purpose is to know the earth as a whole. Land and sea, air and rock, beast and tree combine to form it; and we give some study to each, not to know all about any one, but to see how each controls the rest, and how all work together. This is the science of *geography.* And because we deal with the natural earth and not with its political provinces, we call our subject *Physical Geography.*

The earth belongs to the sun and revolves around it. Thus we must touch upon astronomy. The winds and storms and tides and flowing waters show the working of forces, and so we look to physics for help. Some animals have become used to cold climates, others are fitted to endure heat. Some plants, like the dandelion, are widely scattered, because the seeds have become fitted for travel by the winds. Some live on high mountains, some in swamps and others in deserts. The zoölogist and the botanist will tell us about these, and with their help we shall see the earth as the home of life. To form true notions of our whole planet, because men live upon it and because they have been much influenced by their surroundings — this is the purpose of geography.

Maps. — These are a convenient means of bringing the earth under our eye and of describing it to others. They are miniature representations of the whole earth, or of a

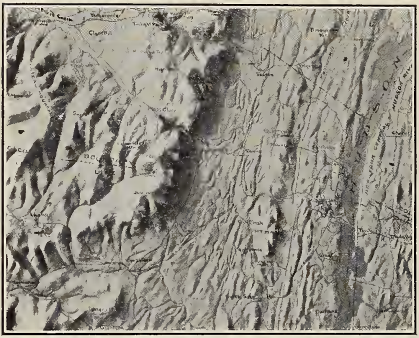


Fig. 4. — Map expressing relief by shading. From a model of the district a photograph was made, and this was copied by the "half-tone" process. Scale, one inch equals five miles.

part of it. In a small-scale map one inch might represent hundreds of miles, as in a common page map of North America. But on atlas sheets containing much detail one inch commonly represents one mile. In such a map many natural and artificial features can be included. The map scale for a closely populated city would be much greater than this. Upon consulting a map the scale should be at once sought.

Fig. 5. — Map expressing relief by hachures. Scale, one inch equals two-thirds of a mile.

Various devices are used to show, not merely the ground-plan or arrangement, but reliefs or elevations as well. This may be done by *shading* (Fig. 4), or by short lines called *hachures* (Fig.

5), or by curved lines known as *contours* (Fig. 6). Hachures are short lines pointing in the direction of the slope of the ground. They are made heavier where the slope is steeper. A contour is everywhere at right angles to the direction of slope. It represents the course one might take if one walked horizontally across sloping ground, choosing one's way so as to go neither up nor down. The outline of a lake is a contour about the valley in which the lake lies. If water should be added to the lake until it is ten feet deeper the new lake outline would be a contour at a level ten feet higher. The contours of a map represent level lines about the sides of valleys and hills, each at a height differing by a regular interval from that of the contour next below it. If the contours are crowded, the slope is steep. If they are far apart, the ground is nearly level.

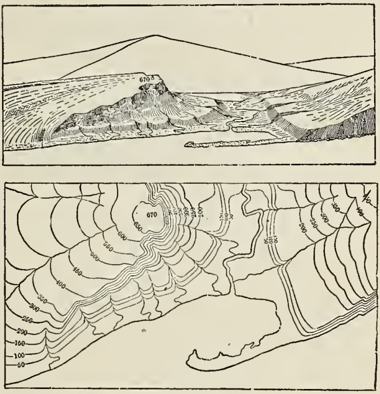


Fig. 6. — The upper figure represents a sketch of a river valley, with terraces, and of a high hill, encircled by a cliff. The same features appear in the map beneath, the slopes and forms of the surface being shown by contours.

Models are relief maps, and are thus more true to nature, if well made, than flat maps. Many models are deceptive and harmful because the heights and slopes are so exaggerated as to teach untruth; but there are also many truthful models, especially of small regions, in which the scale for heights is the same as the scale for

distances. A globe is the most general map, and it may be smooth, or wrought in relief. Pictures are of use in geography. They show smaller areas, but in greater detail. Specimens are in some ways best, for they are actual parts or products of the earth. We illuminate maps, models, pictures, and specimens by records of travel, and, best of all, travel ourselves, and thus make geography interesting and real.

CHAPTER II

THE ROCKS

In the preceding chapter we have seen that the processes of change have much to do with the rocks which make up the earth's crust. Hence it is useful for us at this point to study in an elementary way the origin and characteristics of the principal kinds of rocks. We shall then be ready to take up in detail those great forces which are daily modifying the soils, the land forms, and even the very extent and shape of the lands.

The earth's crust. — The term *crust* dates from the time when the interior of the earth was supposed to be in a molten and liquid condition. As this is not now believed to be true, the word is not wholly appropriate, but it is still used as a convenient designation for the outer part of the globe, with which geography particularly deals.

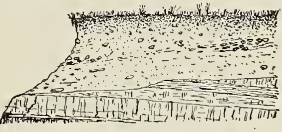


Fig. 7. — Ideal cutting, or "section," showing soil (*s*), the mantle of waste (*w*), and bed-rock (*r*).

Nearly everywhere there is a blanket of soil and stony waste. On the very surface there is commonly a true soil, in which plants will grow. Below is clay, sand, loam, or gravel. Under these loose and uncompacted materials, and often rising out of them in ledges and mountains, is the hard and firm *bed-rock*, which continues to great depths, or until we come to the unknown conditions of the earth's interior. Soils are commonly formed by the

breaking down of the bed-rocks, and by mixing the fine rock waste with vegetable matter. Their formation will be studied in Chapter IV. We must here take up the rocky foundation beneath, and see of what materials rocks consist, how they differ in appearance and arrangement, and what are some common varieties of rock. Thus we shall consider the composition, structure, and kinds of the common rocks.

Rocks are composed of minerals. — Chemists have found between seventy and eighty substances which they have never been able to resolve into anything more simple, and these they call *elements*. It is possible that some of them may yet be found to be of more than one original substance, and new and obscure elements are occasionally discovered.

These elementary substances are in nature usually combined, and a union of two or more of them gives us what we commonly call a mineral. Thus iron and sulphur are elements, and united in certain proportions form the mineral iron pyrites. A union of the two elements, silicon and oxygen, gives us the familiar mineral quartz. Calcium, carbon, and oxygen unite to form the mineral calcite. Pure carbon may form diamond or graphite, and these we may call minerals, though they contain but one element. Very often minerals, of which there are hundreds of kinds, occur in the form of *crystals*. These crystals may be large or small, and perfect, or only of imperfect and partial forms. In other cases minerals are without special forms, or *massive*. The same mineral may often be either crystalline or massive, as quartz.

The student is now ready to learn that minerals, combined in numberless ways, form rocks. Thus if coarser or finer fragments or crystalline bits of quartz, feldspar, and mica are found intermingled, the resulting mass is a rock, and with these special minerals the rock is a granite. If the chief mineral in a rock is calcite, we have a limestone.

This principle will be further illustrated as we proceed with this chapter. Let the student lay hold of the great primary fact, that out of elements are formed *minerals* and that minerals combine to form *rocks*. Thus is built up the whole of the earth's crust.

General arrangement, or structure, of rocks. — We must now take the bed-rocks and divide them into two great sorts. This is not a complete division, for the geologist would find many kinds, but the student of physical geog-

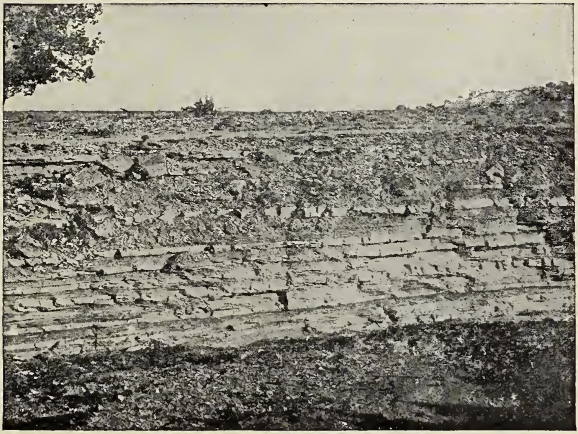


Fig. 8. — Stratified rocks seen in the bank of a creek. Layers of limestone are separated by layers of soft shale.

raphy will have the greatest help in knowing these two classes.

Over large parts of the lands the rocks are in layers, and these layers are horizontal. The student will remember quarries in which the layers, each a few inches or a foot or two in thickness, lie tier on tier. Some are harder and some are softer and they may be of many colours, but they

are either sandstones, shales, or limestones. They were originally formed as layers of mud or sand in lakes or seas, and have since been hardened into rock. In other places the same kinds of rocks, with the same layers, or *beds*, are found inclined at various angles with the horizon, and sometimes completely on edge. They were once horizontal, but disturbing forces have been at work. Whether horizontal or inclined, such rocks are called *stratified* or *sedimentary* rocks, because they occur in layers, or strata, formed as sediments in water. They are often called *fragmental*, because made of the broken pieces or waste of yet older rocks.

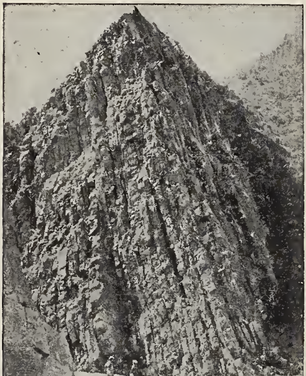


Fig. 9. — Limestone strata which have been upturned in a mountain.

In other places the surface rocks are not in layers, and are neither sandstone, shale, nor limestone. They are often crystalline and have come to be what they are in ways too complicated and various to be explained here. Many of them have cooled from a much heated, or from a molten, state; and they are called *igneous* or *crystalline* rocks. Granite may be taken as a familiar illustration of this class. They are more likely to appear at the surface in mountain regions, but they exist everywhere at some distance underground. This will be more fully explained in Chapter XVI, but we must here observe two or three great general facts about the structure of the earth's crust.

(1) Nearly everywhere there is a surface cover of soil, and often below the soil a mass of loose, stony sub-soil. (2) Bed-rock occurs in some places at the surface and always may be found below the cover of soil and stony waste. (3) Beneath the seas, if we could go down through the muds at the bottom of the water, we should find bed-rock. (4) Wherever we find stratified rocks we can be sure that if we could dig or bore to the bottom of them, we should find the unstratified or crystalline rocks. The igneous or crystalline rocks, therefore, make up the larger part of the earth's crust, but over them in vast regions the stratified rocks lie as a cover.

Sandstone and conglomerate. — Sand may be produced in several ways, but is always the result of crushing or grinding some older rock. Waves along the shores of oceans and lakes are a highly important agent for making sands, although rivers are also effective in wearing the rocks and in carrying off and depositing the waste. In former times the glaciers and glacial waters made and accumulated vast deposits of sand in North America and Europe, and they are still at work in some parts of the world. Any substance that will act as a cement among the grains of sand will turn the mass into *sandstone.* Sometimes the cement is calcium carbonate, sometimes an oxide of iron, and occasionally the hard mineral silica or quartz is dissolved and redeposited as a cement among the grains of sand. The grains may be coarse or fine, and the resulting stone will have a corresponding texture. If the sand has been rolled for a long time on a shore, the softer fragments will have been reduced to fine powder and have been floated away, and the sand will consist almost wholly of grains of quartz, which all have a glassy appearance, and indeed such sands are often used for the production of glass.

Sandstones may have various colours, as gray, bluish,

brown, or red. The colour depends largely on the mineral which serves as a cement. Some sandstones are firm and hard and resist weathering and pressure, thus forming good building-stones. Others crumble readily, and thus return to the former condition of unconsolidated sands.

The same forces that make sand often produce gravel, consisting usually of a mixture of sand and pebbles. When a mass of gravel is subjected to cementing, the resulting firm rock is called a *conglomerate*, or sometimes a *pudding-stone* (Fig. 10). In such a rock the colours and other qualities of the parent rocks are well preserved in the mingled assortment of pebbles brought together in the new rock.

Fig. 10. — Conglomerate.

Sandstones and conglomerates are porous, as may be shown by weighing a dry piece, then soaking in water and weighing again. When such a stone absorbs water and freezes, expansion results, and the rock is weakened and may in the end fall apart. Such rocks serve as underground reservoirs, not in the sense of affording large or cavernous openings, but being everywhere porous, may hold large amounts of water, petroleum, or natural gas.

Shale. — There is much very fine-grained, soft rock, which splits readily into thin leaves along its planes of bedding. In an exposed ledge, these fragments and slivers of such rock will have formed a slope of sliding waste, and

such waste, sometimes used for mending roads, may swiftly turn into mud as rain falls on it and vehicles crush it. We call such rock *shale*, and, like the sandstone, it consists of small bits of crushed or worn rock bound together (Fig. 11). The differences are: first, that the shale often contains much of the fine, smooth substance (an aluminum silicate) which is known as *clay;* and, second, that the other minerals in the shale are more finely pulverized than the grains in a sandstone. The shale was originally mud spread out on the bottom of a lake or ocean.

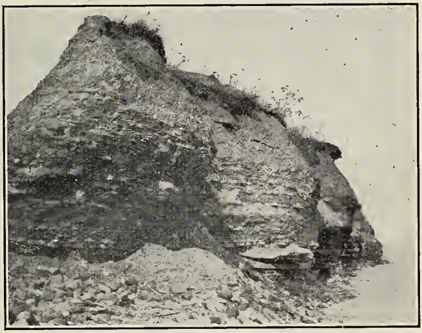


Fig. 11. — Shale at Port Credit, Ont.

Limestone. — A soft mineral, known as calcium carbonate, makes up the bulk of this rock (Fig. 12). It may have various colours, due to impurities which it contains; hence we see blue, gray, yellow, and black limestones. A very pure and light gray or white limestone, called *chalk*, occurs in England. It is soft and fine-grained. Limestone is used for building, and is often "burnt" for quicklime. The burning changes the calcium carbonate to calcium oxide or *lime*. Limestone will dissolve more readily in water than most other rocks. It was originally made by the deposit of the hard parts of lowly creatures. Such animals unconsciously gather dissolved calcium carbonate from the waters in which they live, and

build it into shells. Thus we see how limestones are brought together, and how they may waste and disappear again.

The four kinds of sedimentary rocks described are not always sharply marked off from one another, for sand or

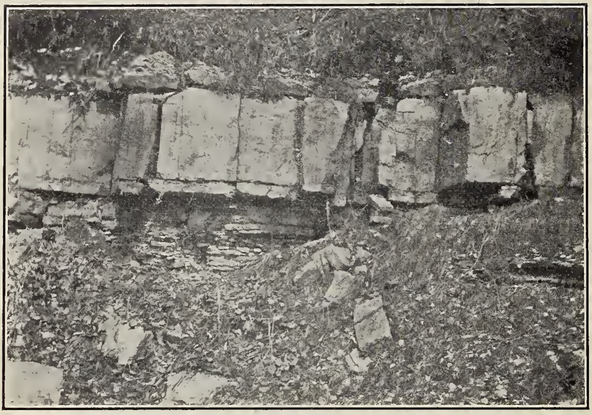


FIG. 12. — A limestone cliff at Napanee, Ont.

clay may be mixed with the gravel of which the conglomerate is formed; there may be clay or carbonate of lime in the sandstone; and clay or sand may be mixed with the limestone, as the sources of the materials varied while the sediments were laid down.

Metamorphic sedimentary rocks. — A sandstone may be so changed, or metamorphosed, by pressure, aided by heat and by solution, as to become very compact and hard, and to show no longer the separate grains of which it was originally formed. Such a changed sandstone is known as a *quartzite*.

Shales, subjected to the same forces of change, may also become hard and resistant to weathering and are then

known as *slates.* Slates split readily into thin and smooth sheets, which are much used for roofs and in some ornamental work. It must not be supposed that slate splits along the original planes of bedding. Rather, these have often disappeared under great pressure, and the new divisions are on what are known as *cleavage* planes.

If a limestone is metamorphosed, it often becomes wholly crystalline in its internal structure: it loses in like manner its old bedding planes, its fossils disappear, and we call the resulting rock a *marble.*

Granite. — Among the rocks formed by cooling from a melted condition, like the lava of a volcano, there are some which have never reached the surface of the earth, but have halted at great depths and have cooled exceedingly slowly. This prolonged cooling gave the constituent minerals time to assume crystalline forms. *Granite* is the most widespread of these rocks, as is seen in northern Ontario, at Muskoka, or the Thousand Islands (Fig. 13). As granite is common among our field boulders and is used for monuments and in building, it may be taken as the type of the deep-seated volcanic rocks, which have been exposed at the surface of the earth by the removal, through the ages, of the overlying rocks.

Fig. 13. — Granite

The chief minerals in the common granite are three. If the student will look carefully, he will see glassy bits of a very hard mineral. This is *quartz*. He may also see a pink, greenish, or white mineral. This is *feldspar*. There are also scales, often very small, of the shiny, thin-splitting mineral known as *mica*. These three minerals are massed together in finer or coarser fragments, to make up the rock. Anything that will tear these mineral bits apart will cause the rock to break down. One of the three, the feldspar, decays slowly under the weather, and much of it becomes in time a smooth clay.

While granite is much the most common of the eruptive rocks in Canada, many others are found, especially rocks with less silica than granite and often with a green or gray colour, such as that which carries the nickel ores of Sudbury, or the rock which is the source of the silver of Cobalt.

Gneiss. — The commonest rock in northern Canada is *gneiss*, which covers more than a million square miles of territory and is to be found as field stones over all southern Canada east of the Rocky Mountains. If it is examined, the same minerals will be found in it as in granite, — quartz, feldspar, and mica, — but with a special arrangement. The mica plates tend to be parallel, the whole rock has a somewhat banded look, and if you attempt to break it with a hammer, it cleaves easily in the direction of the mica plates, but not across them. The splitting is not as smooth and regular as in slate, and the structure is called by geologists *schistose*. Gneiss is a metamorphic rock. The student should remember that not only sedimentary rocks like shale may be metamorphosed, but igneous rocks, as well, may undergo a great variety of changes. Thus all stages may be found from granite, in which the grains of the different minerals have no particular arrangement, to gneiss, which is made up of thin sheets of the same min-

erals. The gneiss has been formed from granite or related rocks by a squeezing and rolling-out process in mountain building. The grains of the granite have been crushed and broken down, and the parallel arrangement produced by solution and recrystallization along the directions of least resistance.

CHAPTER III

RIVERS, VALLEYS, AND LAKES

Terms. — We begin our study of rivers by looking at a narrow valley. We often call such a valley a *gorge*, referring to its depth, or throat-like form; or a *ravine*, a word which means a narrow passage worn by swift waters. A *gully* is a small ravine, like a deep ditch; *canyon* is commonly used of great gorges in the West; while *gulch* is a name often given to gorges in Western mining regions. *Glen, dale*, and *dell* are somewhat poetic words for small valleys secluded among hills.

Fig. 14. — The Grand Canyon of the Colorado River. The cliffs and terraces above are carved from strata, hard and soft. The depths of the gorge are in granite.

A gorge. — Let us choose any gorge, large or small, which we know best, and enter it. No two are alike, yet some of the same things are seen in all. It may be 50, 100, 300, or 500 feet deep. If we are among the Western mountains and plateaus, there are some greater gorges,

even to a mile in depth. The gorge may have vertical walls on both sides. If so, we nearly always find the solid rocks exposed, and these rocks often consist of layers or beds. The beds vary in thickness from an inch or two to several feet, and often some are harder than others. In this case they stand in relief, while the soft beds are crumbling away. If the rocks are not much decayed, they often show even faces of considerable size, standing up like a wall of masonry in which each block has been smoothly dressed. Such faces are caused by straight cracks or partings in the rocks called *joints*, and when the rocks lie in horizontal beds, the joints are almost vertical. They make it possible for gorges to have perpendicular cliffs. Two sets of joints commonly cut each other nearly at a right angle; hence it is that niches and buttresses in great variety often develop along the sides of a gorge.

Fig. 15. — A ravine at Scarboro Heights, near Toronto.

But the walls are not usually vertical from bottom to top. We may often climb over a slope of waste that has fallen from above. Such a slope of waste is called a *talus*, because in form it resembles the ankle. It may consist of fine, sliding fragments not yielding secure footing; or we may find a rough but solid path over large blocks of rock. Whether the talus be steep or not, and whether it be of fine or coarse material, depends on the

nature of the rocks in which the gorge is cut. Rising from the top of the talus is often a vertical cliff, at the foot of which one may pick one's way for a long distance without finding a path to the top.

Most gorges have more or less sloping sides. This is due partly to the talus, as already described. It is also caused by the crumbling of the upper walls, as blocks of rock are wedged off by frosts or pushed down by the growing roots of trees, which in such places thrust themselves into cracks and apply great pressure. A gorge with evenly sloping sides is often called V-*shaped*, and the V is narrow or broad, according to the amount of wasting that has taken place.

FIG. 16. — Milk River Canyon and Falls, Elko, Crow's Nest Pass.

A gorge may have in general the V form, but may show some irregularities. If a layer of hard rock ten feet thick lies between softer beds it will stand out and form a small cliff on the slope. Thus we may have short slopes alternating with low cliffs on the sides of the gorge. The

cliffs mark the hard beds, and the slopes are formed of waste veneering the edges of the soft beds. If the gorge is excavated in softer material, such as clay or sand, we may find very smooth and symmetrical slopes perfectly illustrating the V form. Such slopes show inclinations of 30° to 40° with the horizon.

A multitude of small gorges cannot be noticed here, but they are of local interest and are of value to the students of geography. As examples of great gorges in the East we may name the Saguenay, the Ottawa above Matawa, and the Hudson in the Highlands. All these are flaring and of considerable age. The Niagara, the Credit, and the gorge at Dundas are examples of younger, steep-walled gorges. The Kicking Horse, Thompson, and Fraser canyons of British Columbia and the Grand Canyon of the Colorado are examples of the deep river gorges of the western side of the continent.

The stream. — Along the bottom of every gorge is a stream channel. In it may flow a great river or a brook or only a temporary torrent. The stream is there because the slopes of the land guide the water that way, and the stream may thus be said to exist on account of the channel. But in an equally important way the gorge exists because of the stream, for the stream is in fact the maker of the gorge and is still at work on it, deepening and enlarging. The stream is often a roaring torrent in April and May, and only a rivulet making its way among the stones in August or September. In many ravines the bed is dry during the summer months, except after a heavy shower or a long rain. Then the water quickly gathers from the fields, and rolls yellow and muddy where just before a dry path led up over the pebbles of the stream bed. This suggests that during the breaking up of the spring, and after the heavy rains of summer and autumn, the stream does most of its carrying work.

If the bed of the stream shows a floor of rock, it is effectively carrying away the waste which is supplied up-stream by the breaking up of rocks. The flood current is so swift and strong in volume that little rocky rubbish can rest in its path. This also means that the rocks of the stream bed are exposed to wear, whenever the current is strong. They are filed down by the sand and pebbles that sweep across them; their surfaces are dissolved and the fine matter is borne away. Flakes and blocks of the rock loosen by frost in winter, and are hurried off by the floods of spring. Thus the gorge is growing deeper by the wearing of its floor.

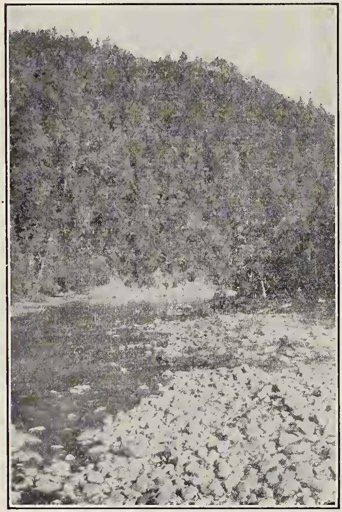


Fig. 17. — A small river at low stage. The water is clear. The shore at the bend shows bed-rock, but the river bottom near by is covered by loose blocks (boulders) which have been rounded by rolling.

But on both sides of the stream will often lie banks of waste at the foot of the cliffs. These will be more or less attacked, according to the power of the current. And at some points of less slope the bed of the stream will be covered with shingle, or coarse, rough waste. And in some still pools, sand and mud will gather, until the down-stream rim of the little basin is cut away. Thus the bed will be protected at some points and subject to wear at others. Depressions

are gradually filled, jutting ledges are worn away, and the bed of the stream gains a smooth grade.

If we find the floor of the stream covered with waste, this means that the crumbled rocky matter is supplied faster than the stream can carry it away. Thus a river or brook may be *overloaded* — that is, so charged with land waste that instead of filing the rocky channel, it casts down a protecting blanket of mud and stones upon it. This, however, does not happen so often in gorges as along the bottoms of open valleys where the flow is less swift.

It will be noticed that some of the stones in the stream bed are angular, and that some have the corners reduced, or are well worn and rounded. These differences depend on the varying distance along which the current has pushed and rubbed the fragments. All the finer rock flour thus made has been easily swept down the stream and is resting in the banks, or has been carried out and spread over the floor of the sea.

These are the ways in which a stream works on the bed of its channel: by —

1. Filing with sand and pebbles.
2. Dissolving rock by the water.
3. Ice-push of blocks of rock in the spring.
4. The heaving of blocks by water freezing in cracks.

And also, as a carrier, the stream removes the rock chips its tools have loosened. Little by little, year by year, century by century, it works away, grinding and sawing its bed and making the gorge deeper.

Sources of the water. — Having studied the gorge and the work of the water flowing in it, let us inquire for the sources of the water. It all comes at first from the sea, or in less degree from lakes and rivers, by evaporation, by the formation of clouds and the fall of rain. On all land surfaces the water tends to gather, to flow along the lines of greatest slope, to form rills at first and then

larger streams. As soon as a stream of any size has formed on a sloping surface, gorge-making begins. But rain-water does not all flow directly into surface streams. Much of it soaks into the soil and often deep into the rocks, and comes out in the form of springs. The journey underground may cover a few rods or many miles. Great caverns may be made by solution and by wear of the waters, and springs of great volume, even to thousands of gallons a minute, may boil up at the surface and at once set in motion a large surface stream.

Fig. 18.—Ice-jam on the Red River, near Winnipeg.

In regions of cold winters much water lies on the surface as snow until the coming of spring, and then melts quickly. Thus floods are larger, and more valley-making is accomplished than would be possible if the water fell as rain and ran freely away after each storm.

As we have just seen, only a part of the falling rain runs directly away. If the soils and rocks are porous, or the surface is flat, or the air very dry, less runs away than if the rocks are hard, the surfaces steep, and the air moist. Hence it is that the percentage of *run-off* to the entire amount of rain varies from one-third or two-fifths in the East to one quarter or very much less in the dry regions of the West.

River basins. — The amount of water forming a given stream also depends on the size of the *basin*. The basin of a river includes all the land surface which inclines towards

it, and whose surplus waters enter the ocean or trunk stream by it. A river, then, includes all its branches however small, and a river system is a tree-like group of streams reaching down to the ocean by one trunk.

Divides. — The boundary between the basins of two adjoining streams or stream systems is called a *divide*, because the water falling as rain is there divided, part of it going to one stream and part to the other. A divide is the higher land forming the watershed or water-parting between two river basins. It may follow the crest of a ridge, high or low, or it may traverse a plain so level that its course is uncertain or even variable. The rivers flowing from the north into the Great Lakes often rise in flat, marshy ground, so that the divide from the waters flowing into Hudson Bay is indistinct. There are even lakes just on the divide which have two outlets, one towards the St. Lawrence system and another towards the Moose River, which flows into Hudson Bay. It is stated also that small boats may, in high water, pass between the head-waters of the Mississippi and the Red River. In high mountain regions where the divide is usually a sharp edge, it is rarely straight for any distance, but is full of sharp curves and zigzags. As there are divides separating river systems, so there are subordinate divides between different branches of the same system.

Waterfalls and rapids. — These are common in gorges. A series of falls with alternating rapids will often be found. Water pouring over single beds or steps of the rock forms low falls. Strong rapids occur in the Grand Canyon of the Colorado, opposite the mouths of tributaries. These side-streams have brought great boulders down their steep torrent beds, and heaped them in the main channel as barriers over which the trunk river plunges.

Falls of considerable height are formed in various ways. If well-developed joints cross the track of the stream,

the blocks wear away up-stream to a given joint, which maintains a wall over which the water descends. With several joint planes and the planes of bedding, a stairway is often made over which the water cascades to the bottom. If softer beds of rock are capped by a hard layer, the decay of the soft beds and the blows given them by the falling water cut them back and leave the hard sheet projecting over them, thus giving the waters a single plunge to the bottom. This is the way in which the falls at Niagara

Fig. 19. — High Falls on the Kenogami River, below Long Lake.

are formed. There the rocks are nearly horizontal. The falls are about 160 feet in height. Sixty feet or more of the upper rocks are hard, thick beds of limestone. For the most part, the rocks below these are shales or hardened muds and these wear back, as shown in the diagram (Fig. 20). As the foundation is removed, great blocks of the hard, capping rock fall down. Thus the form of the falls changes, and they are receding — that is, the gorge is growing longer at the south end, as the falls slowly move up the river towards Lake Erie. The rate of reces-

sion is four to five feet a year. In such a fall the water strikes the bottom with great force, and tears or wears the rock. Hence a pool is formed. At the base of the Horseshoe Fall, on the Canadian side of the Niagara River. the water is about 200 feet deep. At the base of some small falls in the Ottawa, fine, well-like pools, 6 to 10 feet deep, with vertical rock walls, are seen. These smaller pits in stream beds are known as *pot-holes*, and may be found in the rocky floor of almost any swift stream. They vary in diameter from a few inches to several feet, and, if large, may be 20 feet deep or more. They are drilled down by pebbles or larger stones whirled by the dashing and rushing waters.

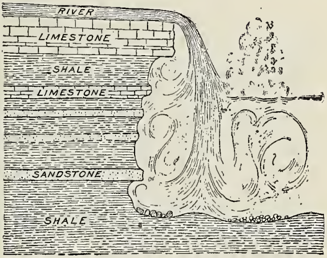


FIG. 20.—Diagram showing the appearance of rocks and stream if a deep cutting (section) were made at Niagara Falls. Upper limestone about 60 feet thick. Water below the fall, 200 feet deep. Boulders, tumbled about by the water, help to wear the shale.

Over the sides of ravines small waterfalls are often found. This means that the main stream has sunk its channel more rapidly and deeply than the side-stream.

Man's use of waterfalls. — Where a stream descends quickly, it is possible to divert it from its bed, carry it a short distance in a canal or flume, and use it to turn the wheels of shops and factories; and the sites of waterfalls are especially favourable for such utilization. The primitive grist-mill and saw-mill are followed by larger undertakings, and towns and cities grow where nature offers power to help man's work. It is about mill-wheels that Ottawa and Sault Ste. Marie have grown up, and a part of the power of the Niagara River, used to generate elec-

tricity, turns the wheels of neighbouring shops, lights the streets of Toronto and Buffalo, and carries passengers on the railways in their streets. Thus a force of nature is linked to the thought and enterprise of man.

Fig. 21.— Kakabeka Falls, near Port Arthur, Ont.

Alluvial fans or cones. — Where a gorge passes into an open valley, one often finds a gathering of land waste having the form of a fan, with the apex pointing up the side valley. From the apex towards the border the slope may be gentle or quite sharp. If the

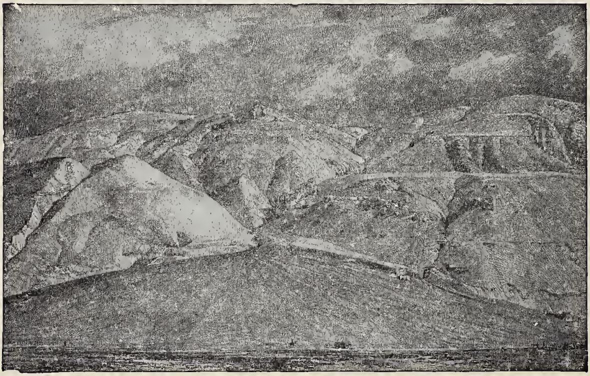


Fig. 22.— An alluvial cone, near Great Salt Lake, Utah.

grade in the side gorge is steep, the swift waters will bring out coarse, bouldery waste and drop it suddenly, making a steep fan. If the grade is less, finer material will come down and be carried farther out on the floor of the trunk valley, giving a wide fan of small slope. The stream flows sometimes along one radius of the fan and sometimes along another, thus building up all parts in succession. Such a body of waste forms a more or less perfect segment of a low cone; hence the term *alluvial cone* is often used. In a mountain land like Switzerland such cones are common and large, and a thrifty people, desiring every possible acre of land for tillage, confine the lawless torrent in a single channel of masonry. Thus they *rectify* the stream, clear away the boulders, and gather good harvests from what seems forbidding ground.

Development of a valley. — Let us now recall the fact that of the gorges of V-shape some are more open than others. The upper slopes of such gorges are often well rounded. As time goes on, much rock weathers away on the sides of the valley, and steadily slips down towards

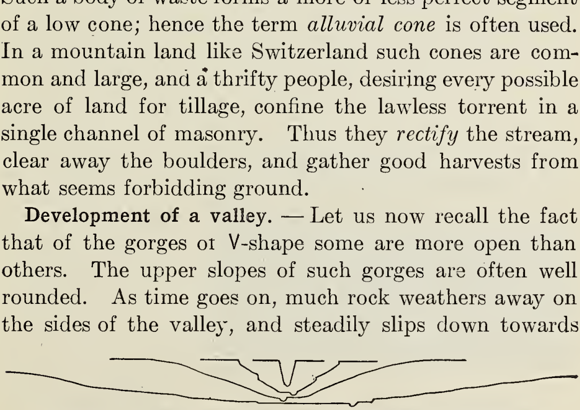


FIG. 23. — Profiles across a valley at different stages of development.

the stream and is carried away. Thus by degrees the gorge becomes an open valley. It is useful to picture to ourselves such growth of a wide valley out of a narrow, steep-walled gorge (Fig. 23). And it is well in our walks and travels to watch for valleys which are neither very narrow nor very wide, but are in middle stages of growth.

Open valleys. — As the valley broadens, the slopes of the valley sides become gentle. Here and there may be steep bluffs of small extent, but the general inclination is quite moderate. On the sides of open valleys rocky ledges may occur, showing that a perfect grade has not been

reached. But with time enough, such ledges will crumble and a perfect slope of soil or coarser waste will appear.

The river in such a valley commonly flows on a floor of waste which it has laid down. Here and there it may cross rocky ledges, giving rise to rapids such as are more commonly seen in gorges. Above each rapid is a stretch of nearly still water, giving us an alternating series of rapids and *reaches*. Hence the *portages* which are so common in canoeing trips, and which form a feature in primitive carriage of goods by water. Even if there are no ledges of rock, there are still alternations of rapid and reach; but these are low-water features only. At a high stage the forward slope of the water surface is nearly even, but there are differences in the current, causing bars of waste to form here and there; and at each of these bars a rapid appears when the flood has passed. It is instructive to study a familiar creek when its banks are full, and to note what little trace remains of well-known deeps and shoals.

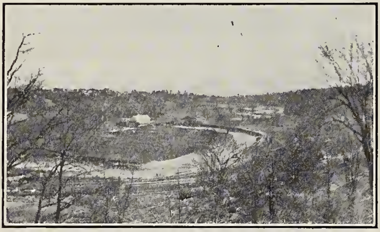


FIG. 24. — The Don Valley, near Toronto.

A large river may be many feet deep, and is often a half-mile or more in width. A few great rivers, like the Amazon, show a width of many miles at their seaward ends. The stream is bordered by banks varying from a few feet to twenty or more in height. These banks are the edges of nearly flat grounds which stretch away to the base of the valley slopes. These are known as *flood-plains*.

Flood-plains. — Commonly the water is confined between the banks, but in the spring, or after great rains, the

stream passes its banks and floods the strips of flat ground on both sides. At such times the river is charged with mud, and a layer of this fine material is spread over the flooded grounds. Thus when the water retires, it leaves them a little higher than before. The deposit consists of fine waste, largely derived from soils of the uplands. It thus constantly adds to the fertility of the lowlands, which bear rank forests, and when these are cleared yield perennial harvests. These lands are easily tilled, and are usually the first occupied in a new country. Their smooth surfaces offer natural grades for the primitive wagon and stage, as well as for the railway of later days. If the stream is navigable, the products of the valley may be easily and cheaply exchanged for needed articles from distant regions. A large share of the population of most countries is found on the flood-plains of rivers. The middle Rhine exhibits one of the most carefully tilled and thickly settled flood-plains of Europe, while Egypt as a habitable and productive land consists chiefly of the flood and delta plains of the Nile. The flood of the Nile is now controlled by the gigantic dam at Assouan recently completed at a very great cost.

Along a large river the flood-plain is higher next the stream, because there the waste first lodges in times of overflow, and the plain slopes gently thence to the valley sides. Such a strip of higher ground, from its resemblance to a dike thrown up to restrain floods, is called a *natural levee*. It often happens that the outer parts of the plain are flooded while long strips of natural levee appear between the back water and the main channel, and therefore the farmers of a great flood-plain build their houses close to the river.

Meanders. — Many rivers, as they traverse their flood plains, swing to right and left in strong curves. Thus the distance from Cairo, Illinois, to the Gulf of Mexico is about

five hundred miles, but by the Mississippi one travels over one thousand miles. The breadth of these swings of the river is from three to six miles. On the outside of the curves there is deep water and a steep bank, at which landings are possible for steamboats. On the inner side is a sloping beach passing beneath shallow water. The river cuts away the outer shore and adds to the other, and thus widens the belt of curves or *meanders,* as they are called from a winding river of Asia Minor. Little by little, however, the tongue of land that reaches into a great bend is narrowed at its base, by the growth of other bends, until at last the neck is cut away, and the river track is shortened. By such a *cut-off* of one of the great Mississippi meanders, the river may be shortened at a given point by fifteen or twenty miles. The curving channel thus abandoned by the current is soon partitioned from the river by the growth of a barrier of waste, and becomes an *ox-bow* lake.

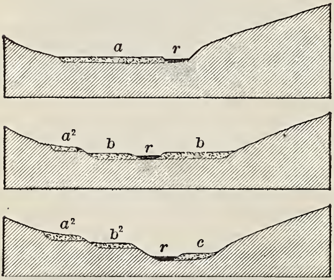


FIG. 25. — Cross-profiles of a valley at three stages of development, to show how river terraces are made. *r*, river. *a*, *b*, *c*, successive flood-plains. *a²*, *b²*, remnants of first and second flood-plains, remaining as terraces.

The Mississippi is taken as an example, but the meandering habit is not limited to great rivers. It is as perfectly seen in rivers of moderate size, such as the Assiniboine in Manitoba, and in brooks, as along the Mississippi itself. The width of the swing will depend on the size of the stream. It may be a few rods for a brook and miles for a great river.

River terraces. — We have seen that in each flood the river spreads a film of mud over its flood-plain and raises

its surface. At the same time it is often sinking its bed. Hence a time will come when flood-waters will not rise on the flood-plain. They will, instead, cut into its edges and trim much of it away, and out of this waste and that brought from up-stream will form a new flood-ground. The remnants of the higher, forsaken plain are known as *river* or *alluvial terraces.* Several sets of them, at successive levels, are seen in the valley of the Connecticut and along other rivers. They are not often important in size, but may afford good sites for single homes or parts of towns.

Deltas. — Gathering its tribute of land-waste from the Appalachian and Rocky Mountains, and from the plateaus and prairies that lie between, the Mississippi River lays down its burden on the plain of the lower valley and at the borders of the Gulf of Mexico. Even its finest mud sinks to the bottom as the flowing river unites with the standing water of the sea, and a shoal is thus built up, to become at last a part of the land. So the river-plain is built higher and is also extended southwards. The growing plain is called a *delta.* The river, building its channel above the adjoining land, breaks through its banks at various points and discharges part of its water by down-stream branches. These are locally called *bayous,* but are more widely known as *distributaries,* a name which distinguishes them from up-stream branches or tributaries. Not only the land, but the sea-bottom, for a long way out, belongs properly to the delta, its materials having come down the river. More than 1000 feet of such deposits were disclosed by an artesian well boring at New Orleans. Two great problems are always presented by the Mississippi delta: To protect the lands from flood, wherefore *levees* have been made at great expense; and to keep an open channel for navigation, wherefore *jetties,* or artificial banks, have been built along one of the *passes* at the river-mouth, to confine and quicken the flow, and thus scour and deepen the channel.

There are no very large deltas in Canada except that of the Mackenzie River where it enters the Arctic Ocean. Its delta is *tundra*, or plain that is always frozen below, though clothed in summer with grass and flowers. The delta of the Fraser River, though much smaller, provides the fertile plain on which stands the city of Vancouver. In Ontario, deltas are still smaller, that of the Kaministiquia, on Thunder Bay, being one of the most characteristic. In the Old World, the Nile, the Po, the Tiber, and the Rhone deltas are notable examples, while the Ganges, the Brahmaputra, and the Hoang-Ho have enormous deltas on the Asiatic sea-border.

Fig. 26. — Delta of the Nile River. Note the fan-shape, with the apex at Cairo. The distributaries are many. Capes are built into the sea at the main mouths. There are many railways, because the fertile soil supports a large population.

Deltas on lake borders. — It must not be thought that all deltas contain hundreds or thousands of square miles or are built on the borders of the ocean. Many are seen on the shores of lakes, and when a swift upland stream is there suddenly checked, the delta will contain sand, gravel, and boulders, and thus be different from the marine delta. Its form will be different also, and instead of the delta surface passing smoothly down to the bottom of the water, it will have an abrupt slope in front. When the stream, pushing for a little way through the shallow water, reaches the brink, its load will

settle and slide down the incline, much as teams and wagons make a *fill* in carrying a road grade across a gorge. The interior structure, if we should slice the delta through, would appear as in Fig. 27. The stream will

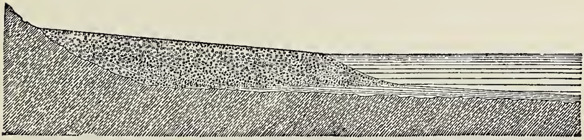


Fig. 27. — Section of a delta made of gravel and sand.

swing from one line to another, building up the delta on different parts of its front, and shaping that front into a series of lobes. All of these features may be seen in miniature after a wayside pool, receiving a wet-weather torrent, has dried away.

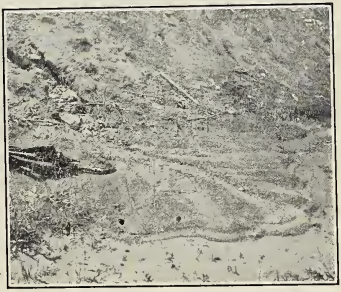


Fig. 28. — Miniature delta. During a rain a pool was formed at the foot of a steep slope of earth. A rill dug a miniature gorge in the slope and washed the waste to the pool, where it built a delta. Before the pool dried away the wind made wavelets, which carved a shore terrace about the edge of the delta.

Young, mature, and old valleys. — These are important terms in physical geography, and we are now prepared to understand them. They are useful because they express the great fact that the forms of the land are changing, or having a development which may be traced, somewhat as we follow the growth of a plant or the history of a town. They are used, as we shall see, not only of valleys, but of other land forms, as plateaus or mountains.

A young valley is narrow, has steep sides, and carries a vigorous stream flowing on an uneven floor. The gorges already named are illustrations. A mature valley is deep, but open also, having flaring sides, and gentle, rounded upper slopes. The valley of the St. Lawrence in Quebec is mature, but that of the Credit River or of the Humber is young.

We have already seen how a narrow valley grows wide and a steep-walled valley becomes open. The floor of the valley is widened by the swing of the river in gentle curves or strong meanders, while the slopes are reduced by all the processes of decay or weathering, as described in the next chapter. At the same time rapids and falls disappear and the river comes to flow on a graded floor. As the slopes fade out, the valleys become wide, the divides low, and the rivers sluggish, and the whole land surface passes into old age.

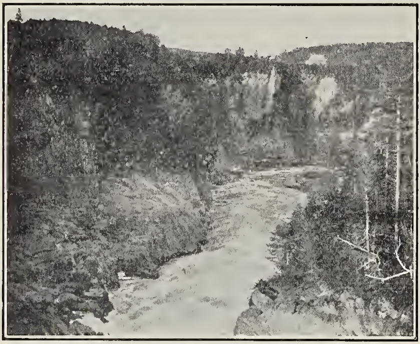


Fig. 29. — Grand Falls Canyon, in British Columbia.

The general work of a river system. — Let us picture to ourselves an elevated plain near the sea, and a branching river system formed upon it. Where the river descends steeply to the sea it will plough a gorge. This gorge will extend backwards, up-stream, branching where the river branches, and its divisions will in time ramify throughout the river basin. While they are growing at the head-

waters, the lower gorge will be changed to an open valley, and this broadening also will extend gradually up-stream. At first there will be remnants of plain between the gorges, but these will grow narrow as the gorges grow broad, and will finally be replaced by crested hills, which will then soften and sink with the flattening of valley slopes. All these changes will proceed from the trunk stream towards the confines of the basin, and at last reach the outer divides separating the basin from other basins. Thus the whole plain will be at first furrowed and made rough, and the ridges between furrows will afterwards be reduced so as to lessen the roughness. In a very long time the entire basin will again be made a plain, but the final plain will be much lower than the original, being but little above the level of the sea.

The great fact is, that the level of the land is slowly reduced and the waste is carried off to the sea-bottom. The uplands of northern Ontario and Quebec are now of moderate height. They were once much higher. The highlands of Scotland are subdued lands, but in past ages they may have towered like the Alps or the Andes. Follow the river from the mountains to the sea. See the waste in talus and fan, terrace, flood-plain, and delta. But much of it has gone beyond the shore-line, and spreads far out to sea. We shall come to it again in our study of the ocean.

Imperfect development of drainage. — If the farmer has a swampy field, he opens a channel or a network of ditches and draws the surplus water away. He may even cut across a rim of higher ground, if the cost be not too great. If human life were longer and he could afford to wait, nature would drain the swamp or pond for him; some stream would head into it and carry away the waters. So, wherever we see water standing on the land in lake or swamp, we must understand that the drainage is still im-

perfect, that the river system has not yet developed its branches in a mature way and taken possession.

Lakes. — These are illustrations of imperfect drainage, and if many are present they stamp a region as having a young surface. Lake basins are depressions which detain the waters from passing directly to the sea. They are made in many ways which cannot be fully described in an elementary book. The greater number are due to the glacial invasion and will be explained in a later chapter. Some, like Great Salt Lake and the Dead Sea, are due to bendings or unequal movements of the earth's crust. Small lakes sometimes occupy old volcanic craters; and we have seen how cut-offs in river valleys form ox-bow lakes. When we study the shores of the sea, we shall observe the making of lakes by shutting off the waters of deep bays. Alluvial cones at the mouths of some Swiss gorges are built across the main valleys, crowd the streams to the other side, and dam the waters coming from above. Landslips and lava floods blockade valleys into which they descend and make small lakes behind them.

Disappearance of lakes. — But we are here most concerned to see how lakes disappear as drainage becomes mature. If the rapids of the St. Lawrence and the rocks of the Thousand Islands were cut away, Lake Ontario would be partly drained, but only in part, because about 400 feet of its depth is below sea-level. But when the Niagara River has finished its work the bed of Lake Erie will be dry, for its lowest point is more than 100 feet above the surface of Lake Ontario. This will take a long time, but the process is already complete with many small lakes, which once existed, but whose bottoms are now meadows.

This brings us to the second important way in which lakes disappear. Streams bring down their load and build deltas at the edge and spread the mud over the entire bottom. Water-loving plants grow about the edges

and help to fill the shallow places. Small shell-making creatures abound in some lakes, and their crumbling remains form a white deposit of calcium carbonate or shell marl. Trees and leaves add their part, and at length the basin is full and the water is displaced. The sawing of outlet channels and the filling of basins are responsible for the disappearance of many lakes. All stages of the process may be found by the observing student in most parts of Canada.

A delta is rapidly encroaching on Lake St. Clair (Fig. 30). The south end of Lake Lucerne in Switzerland is diminishing by the growth of a delta on which Flüelen and Altdorf stand. A similar shortening occurs where the Rhine enters Lake Constance and the Rhone, Lake Geneva.

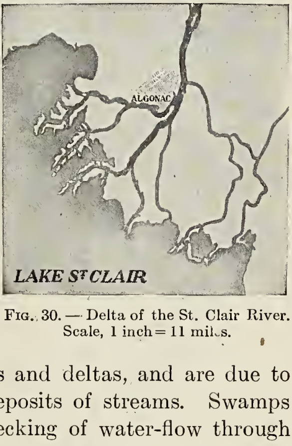


FIG. 30. — Delta of the St. Clair River. Scale, 1 inch = 11 miles.

Swamps. — Marsh lands are marks of imperfect drainage, and they often are due to the nearly completed filling of lakes. Others occur on flood-plains and deltas, and are due to wanderings and irregular deposits of streams. Swamps are often caused by the checking of water-flow through the growth of trees and shrubs, and they disappear when forests are cut away. Swamps caused by the beaver-dams have a similar history.

Imperfect drainage on new lands. — Much of the flat land along the St. Lawrence was formerly part of the sea-bottom, and has been turned into land by the gentle rising of the continent. The streams have not had time to cover the surface with their headwaters. Hence the rain

Fig. 31. — The river systems of North America.

falling on the smooth areas between the streams, evaporates, or drains off slowly underground. The same is true of the plain drained by the Red River, except that this formed the bed of a lake and became land by the draining of the waters.

River Systems

The Mississippi system. — One of the great river systems in North America is the Mississippi with its tributaries, draining almost all the central United States between the Appalachians and the Rocky Mountains; but only a small part of Canada, in southern Alberta, contributes to its waters. Joined by the Missouri and other rivers on the west and the Ohio on the east, the Mississippi is a continental river, with its myriad torrents in the mountains of east and west, its leisurely stretches across broad plateaus and plains on both sides, to the trunk channel, down which the ceaseless stream of water and land-waste pours into the Gulf of Mexico.

St. Lawrence system.[1] — The Great Lakes are usually regarded as expansions of the St. Lawrence River. A great river system drained eastwards over this region before the lakes were in existence. Portions of its valleys were deepened by the ice, and other portions were block-

[1] The St. Lawrence Lakes	Length	Average Width	Area	Height above Sea
Name of Lake	Miles	Miles	Square Miles	Feet
Superior	420	80	31,420	602.75
Michigan . . .	350	60	26,000	578.75
Huron	270	70	23,780	576.75
St. Clair	25	25	360	570.75
Erie	250	38	10,030	566.75
Ontario	190	55	7,330	240

aded by rock-waste, and so the lakes came into being. In this view, the St. Louis River, the Nipigon, the St. Mary's, the St. Clair, the Detroit, and the Niagara, and each great lake, are but different parts of the one great river. The river descends but 26 feet from the Superior to the Huron level, thence 10 feet to the Erie level, and 326 feet by the Niagara River and Falls to Lake Ontario. The gentle reaches and the rapids below the Thousand Islands bring the river to tide-level between Montreal and Quebec. Thence the St. Lawrence valley is occupied by an inlet of the sea. At Montreal the river receives its largest tributary, the Ottawa.

This is commercially the most important inland water system of the world. Here are the ports of Duluth, Port Arthur, Fort William, Milwaukee, Chicago, Detroit, Cleveland, Buffalo, Hamilton, Toronto, Montreal, and Quebec. The greater of these ports vie with New York, Liverpool, and Hamburg in the tonnage of their shipping. Over this route pass the iron ore of Minnesota, and the wheat and corn of the prairies and the plains. Such a body of waters, penetrating the heart of North America may be compared, in its influence on the development of commerce and the shaping of history, to the English Channel and the North and Baltic seas.

Drainage towards Hudson Bay. — The St. Lawrence system drains only a narrow band of country round the Great Lakes. Most of northern Ontario and Quebec send their waters northwards towards Hudson Bay. A series of important rivers, such as the Albany, Moose, Missanabie, and Abitibi rivers, in Ontario, and Noddaway River, in Quebec, flow into James Bay. The greater part of the western plains is drained by the Saskatchewan, which begins with mountain torrents fed by glaciers, flows more gently through the flat land of the prairie, and has its mouth in Lake Winnipeg. The south-

eastern prairies are drained by the Red River and its branch, the Assiniboine, emptying into the southern end of Lake Winnipeg. The Nelson River flows from Lake Winnipeg and carries the combined waters of the Saskatchewan and Red rivers to Hudson Bay. Before railways were built this river system supplied hundreds of miles of inland navigation for the boats of the fur-traders and for stern-wheel steamers, thus aiding in the opening of the country.

Fig. 32. — A scene on the Churchill River.

Farther north the Churchill and Telzoa rivers flow through the forest lands and barren ground beyond the forest into the western side of Hudson Bay.

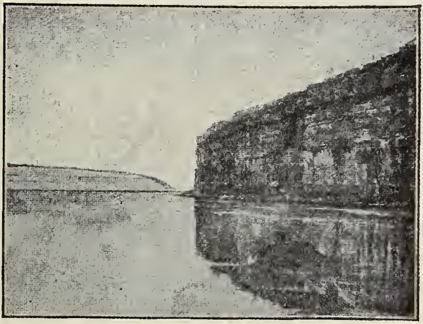


Fig. 33.—The Ramparts of the Mackenzie River, forming a gorge, near the mouth of the Great Bear River.

The Mackenzie River system.—This, excepting the Mississippi, is the greatest river system in North America, and it sends its powerful flood of waters

into the Arctic Ocean. It includes the Athabaska, Peace and Slave rivers, and drains vast areas of the Rocky Mountains, and of the northern plains. Measured from the head of the Peace River, its length is more than 2200 miles, and it bears to the ocean the waters of three great lakes, Athabaska, Great Slave, and Great Bear. The steamers of the Hudson's Bay Company ply for 1800 miles on the Mackenzie River and its tributaries.

Other large rivers flowing north are the Great Fish, or Back River, and the Coppermine, emptying into Arctic waters, and the Koksoak River, draining northern Labrador into Ungava Bay.

Fig. 34. — The Fraser River at Lytton, British Columbia.

Drainage of British Columbia. — The southern part of British Columbia has two great rivers, each rising in the deep valley which runs for 800 miles north-west and south-east between the Rocky Mountains and the Gold Ranges. The Columbia begins by flowing north-west, fed by many glacial streams, suddenly turns south, inclosing the Selkirk Mountains, rests for a time in the narrow and deep Arrow lakes, and then enters the United States, reaching the Pacific near Portland.

The Fraser River commences in the same way as the Columbia, flowing north-west in the long valley west of the Rocky Mountains, turns south also to a point near

the international boundary, and then west to tide water at Vancouver. The Fraser and its largest tributary, the Thompson River, have cut deep canyons through the Coast Range and interior plateau of British Columbia, and thus have allowed the Canadian Pacific Railway a passage to the sea.

Parts of the Columbia are navigated by steamers, but the Fraser is too violent for navigation except at its lower end, below Yale. In northern British Columbia stern-wheel boats ascend the Skeena and Stikeen rivers for about 150 miles, and the valley of the Skeena and one of its tributaries provides an easy way for the Grand Trunk Pacific Railway to reach tide-water.

The Yukon. — The Yukon is the third river of North America for length and size. It flows from White Pass, only 18 miles from the Pacific at Lynn Canal, north-west through the Yukon Territory, and then west through Alaska to Behring Sea, after a course of 2000 miles. It is an important artery of travel and commerce in Alaska and the Yukon Territory, and is navigated by fairly large steamers for 1800 miles, despite the fact that it is closed by ice for more than half the year. It has built into Behring Sea a great delta.

CHAPTER IV

WEATHERING, SOILS, AND UNDERGROUND WATERS

In our study of streams we have seen that flowing water does not act alone in breaking up the rocks and changing the face of the earth. The rocks are attacked in various ways, and reduced to small fragments or to clay.

If the student will search in a boulder heap, he will probably find some piece of sandstone so soft that it will crumble in the hand. Here the cement is losing its hold, and the sand is going back to its old condition. Let us weigh a piece of dry sandstone; then soak it a day in water and weigh it again. We shall find that water has been absorbed, sometimes as much as one-eighth of the weight of the stone. This means that there is free space among the sand-grains, which water or air may enter. Suppose the stone freezes after absorbing the water. Expansion will take place and the sand-grains will tend to be thrust apart, and after many such wettings and freezings, the stone will crumble. Hence a very porous sandstone is not a good building stone for outside work. A little search will discover sandstones, in buildings or other structures, which show scaling. This is one of the ways in which the stone may be destroyed, but the fact most important to remember is that such rock is built out of small separate grains and may return to its former condition.

In shale, the particles are more finely pulverized than in sandstone, and under the rain it quickly turns into mud. Limestone will dissolve in water more readily than most rocks, and so be carried off, leaving any insoluble particles, as sand or clay.

The crystalline rocks such as granite and gneiss consist of several kinds of minerals, and anything that will tear these mineral bits apart will cause the rock to break down. The feldspar decays slowly under the weather, and much of it in time becomes smooth clay, so that the decomposed granite or gneiss may be excavated with a spade in regions where glaciers have not scoured the surface down to the fresh rock.

It is to such breaking down of the rocks that the diversity of the earth's surface, the forms of mountains, and the existence of its mantles of soil are largely due.

Fig. 35. — Weathered sandstone. The rock is composed of horizontal layers, and is divided by vertical joints. The weathering is most rapid along joints and at the divisions between layers.

To a short study of these processes of destruction we now turn. Rocks are broken and worn by river action; other chapters will show how they yield to the friction of glaciers and the pounding of sea-waves. The destructive processes referred to in this chapter are less conspicuous, though perhaps more important.

Surface Wasting

The atmosphere. — Our atmosphere contains much oxygen, a gas which combines readily with most substances. When it unites with iron it causes rust, and rusting involves softening, and a change to dull brown or reddish

colour, in place of the former metallic lustre. Most rocks contain iron in some form, the rusting of which causes the rocks to show stain, and by and by to decay. This is one important cause of *weathering*, a term used to cover the softening and breaking up of rocks which in a number of ways goes on quietly at the surface of the earth. The surface of a stone block or boulder is often thus changed, while the inner parts, if opened to view by the hammer, show the true colour and hardness of the rock. A bed of clay or sand is usually weathered to dull hues above, but remains of a bluish colour below. This change is due to the oxygen of the air, which penetrates all parts not filled by water. Marble tombstones lose their polish after a few years. Rain and air, holding small amounts of carbon dioxide and other gases, dissolve a little of the surface and so remove the lustre. Cleopatra's Needle, now standing in Central Park, New York, was preserved for many centuries in Egypt, because the air there is so dry and pure. But some protective wash had at once to be applied to the surface when exposed to the damper air of the Atlantic coast, especially where mingled with the gases that flow from the chimneys of a great city.

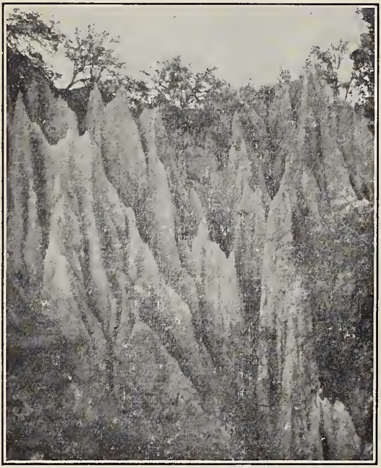


Fig. 36. — A pebbly rock carved by rain.

Rain wash. — Notice a bank of earth just after a heavy shower. The soil crumbles and its grains freely fall apart. There are small furrows or channels down the slope, and rills of water, still running in the channels, are dark with the grains of earth they have been able to pick up. Permanent streams work only on narrow strips of land, but rain soaks and softens the rocks and soil everywhere, and gives the first start to loosened particles. The rain rills begin the great task of carrying which the creeks and rivers continue.

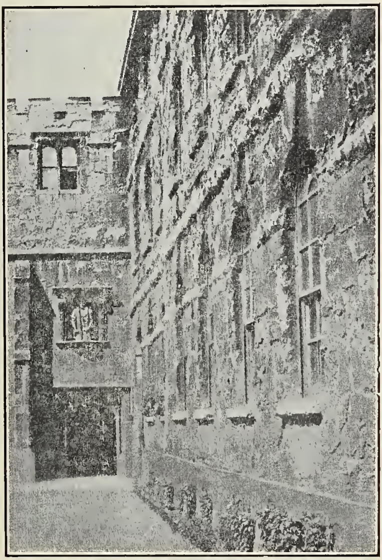


Fig. 37. — Weathering of limestone in the wall of an old building; Trinity College, Oxford, England.

Solution. — If a gallon of water from any stream or well were evaporated, a small amount of solid matter would be found. In a teakettle much water is evaporated, and still more in a steam-boiler, and the inner surface of each receives a hard coating. This solid matter has been dissolved from the rocks by water. Thus, whether we observe that the damp air changes the polished marble to a dull surface or remark that some water is "hard" and other is "soft," we are

noting the effects of *solution* upon the rocks of the earth's crust.

Frost and changes of temperature. — The wasting of Cleopatra's Needle was due not only to the oxygen and other gases of the air, and to solution, but to the freezing and thawing of its moistened surface. Even in summer the heating and swelling under the hot sun of noon, and the cooling and shrinking of night, will make some rocks crack and flake. The student should examine stone buildings, and he will be sure to find cracks and signs of decay of which there was no indication when the buildings were erected. Dr. Livingstone records in his notes such cracking of the rocks of Central Africa, where the noon temperature was 137° F.

Plants. — All trees which have strong tap-roots stir the earth to a considerable depth, and even grasses often send their slender roots two feet into the ground. When plants die, their roots decay, and the process of decomposition produces new substances, some of which strongly affect the rocks. As trees and herbs grow everywhere, thrusting the earth apart by their roots, and mixing with it in their decay, we can see that the influence of plants is almost universal.

A gorge should be visited and a study should be made of the roots of the trees on its steep slopes and crests. The roots thrust themselves far into the joints and planes of bedding and rend the rocks apart with great power. At the same time mosses mantle many rock surfaces, keeping them moist, and thus helping water to do its work of destruction.

Animals. — The gopher and the prairie dog are widely found on the western prairies. They dig deep burrows, and cast up at the mouth of each one a mound of earth. Thus a large work is done by them in stirring the earth at its surface and a little

below. Of similar effect is the work of badgers and woodchucks and the elaborate system of tunnels made by ground-moles. In like manner crayfishes burrow deeply, and it is said that they have even caused breaks in the levees of the Mississippi River. Beavers and musk-rats carry on their operations at the borders of streams and the beavers cut much small timber, flood many acres by their dams, and have been known to excavate canals

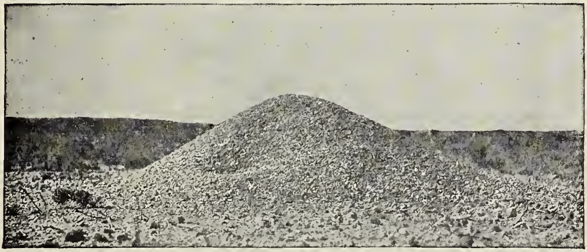


FIG. 38. — Ant-hill, Arkansas Valley, Colo. Height, about one foot.

for floating wood to their ponds. The hillocks built by ants are composed of sand-grains brought from tunnels underground, and are in some places so numerous as to make a dotted pattern on the hillside.

Near the close of his life Darwin took to his publisher a manuscript of which he spoke in modest terms. It was published, and has become famous, because it shows how large a work the common earthworm does in pulverizing the soil and mingling the substances which compose it. And we must not fail to see in man himself a vigorous modifier of the earth's surface. He causes changes in many ways, but the most important is by clearing the forests and by turning up the earth with the plough Thus rains, frosts, winds, and surface streams, all are given a chance to work, and the decay and transfer of

the materials of the earth's surface are much hastened.

Creep. — When the farmer runs a side-hill plough along a steep slope he turns the soil towards the bottom of the hill, and in so doing he assists in a work on which nature is ever engaged. As the friction between particles is lessened by the entrance of water, and as the soil is slightly moved by cooling and warming, freezing and thawing, its weight pulls steadily in one direction, and this causes a real but imperceptibly slow down-hill movement which we call *creep*. On steep mountain sides this of course progresses less slowly than on ordinary sloping fields.

Fig. 39. — Shale broken by down-hill creep.

Rock falls. — Where rivers, or the sea, are undermining a cliff, or where a cliff has in any way been formed, masses of the upper rocks come to be insecurely supported. Frosts and roots use their thrusting power, joints are opened, and blocks tumble to the bottom. Thus gravitation aids in the destruction of the lands.

Avalanches. — Masses of snow, losing their poise on high mountain slopes, go down with fearful speed and destructive power. They cut great lanes through the forests, and sweep rocks and earth in their course. The Swiss

people set rows of strong stakes across the slopes where avalanches are in the habit of starting, and thus check the snows above their farm plots and villages.

Thickness of land waste. — When a surveyor or contractor estimates the cost of making railway cuttings or canals, he takes into account the thickness of the earthy mantle that covers the rock. The excavation may be partly in waste and partly in rock, according to its depth and the thickness of the waste cover. The latter varies much from point to point. In many valleys the deposits of clay, sand, and gravel are several hundred feet deep. But often on the uplands and sometimes in valleys the rock comes to the surface. Thus the earthy cover varies from slight to great depth, but if we dig deep enough the solid rock will be found.

FIG. 40. — Avalanche tracks through a forest of fir, northern Montana. The mountain side was worn smooth and steep by a great glacier, and bears little soil.

Local waste. — If a rock decays in its original place, as through wetting and drying, freezing and thawing, and the agency of roots, the earth and soil may be called *local*. Some of the materials once forming the surface will have been dissolved and carried away, but the parts not readily dissolved will remain. Hence the rock con-

trols the soil, as in many parts of the United States and Europe.

Transported waste. — The soils of many of the valleys of British Columbia have come down from the mountains by the wash of rivers. The soils of deltas, such as that of the Mississippi, may have come from great distances, from the Rocky Mountains, the Great Plains, and the Appalachian region, transferred by the river and its tributaries. The earthy mantle of southern Ontario is largely composed of rock-flour and stones brought from northern Ontario or even from Labrador by the great glacier that moved south and south-west from those regions. We thus speak of *transported waste,* or *drift,* a word especially applied to material moved by glaciers.

Land Forms Due to Surface Wasting

Mountains. — The mountains of the Eastern Townships of Quebec, and of northern Ontario do not stand forth as mountains because they have been lifted above the surrounding country, but because the surrounding lands have wasted away, and their materials have been carried to the sea. The country has grown rough in time, as a smoothed surface of a coarse-grained wood does, after years of exposure to the weather. It is, however, true that many moun-

Fig. 41. — The Crow's Nest Mountain, Crow's Nest Pass.

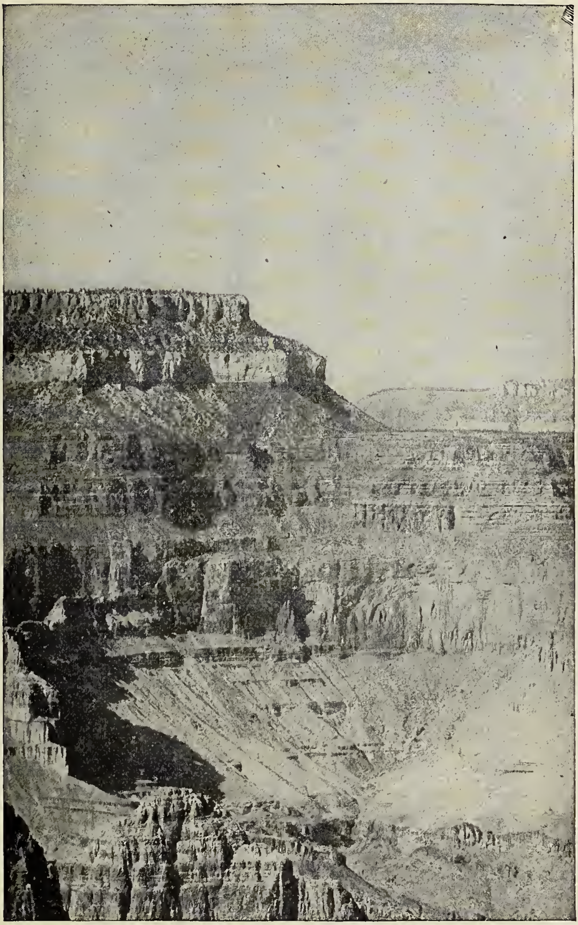


Fig. 42. — Rock ledges (limestone and sandstone) and waste slopes (concealing shale); Grand Canyon of the Colorado River, Arizona.

tain masses are higher than the adjoining lands ever were. The Rocky Mountains, for example, have always been much higher than the Great Plains, though both have suffered uplift.

Rock ledges and waste slopes. — Almost every mountain or steep hill shows us ledges, or sometimes long shelves of harder rock, which resist the destroying forces

FIG. 43. — The Ten Peaks, near Laggan, Alberta.

we have been studying, while between the ledges are smooth slopes of soil or coarser rocky waste. In time the ledges will crumble away and the slopes will take full possession. These changes are seen to good advantage in many parts of the far West, where the rocks are horizontal, with harder and softer layers, and there is so little vegetation that the forms of the hillsides are fully exposed to view. Sometimes the upper surface of a hori-

zontal hard bed is bare over a considerable area, while the edge is kept as a cliff by the weathering of soft beds below. Such a shelf or table is called a *mesa.* If the broadening of valleys divides a mesa so that part of it stands as a separate hill, the hill is called, in the same western region, a *butte* or *mesa-butte.*

Sharp peaks and rounded summits. — Any good picture of the mountains of eastern America will show how rounded and subdued the mountain tops are. Long ages of weathering have caused this. But the Canadian Rockies, the Alps, and the Pyrenees bristle with sharp ridges and peaks. These mountains have existed long enough to have deep narrow valleys and steep slopes made by weathering, streams, and glaciers, but not long enough to have their sharp crests subdued. These are examples of the ways in which wasting controls the shapes of the earth's surface.

Soils

What soil is. — The student should observe any excavation that penetrates a few feet below the surface. For a few inches, or one or two feet, the material will be dark in colour and mixed with living roots and decayed vegetable matter. The latter may be present in small measure, or it may abound, even making the surface matter almost black. This superficial layer is called the *soil* (Fig. 7). It is the support not only of the natural growth of land plants, but of all cultivated plants. Its origin is therefore interesting, and no other material consideration is so important to our race as its preservation.

Origin of soil. — It will be observed that we have carefully avoided using the word "soil" in writing of the general waste mantle, although it is often loosely so used. The student should distinguish clearly, and use it only of that outer layer of earth which is specially fitted to sup-

port life. Like the waste that lies below it, the soil is derived from the solid rocks, but it alone is enriched by the addition of vegetable matter. The chief foods of growing plants are water and certain substances contained in air, but they need also something contained in rock waste, and the decaying vegetable matter in the soil helps to prepare the waste for their use.

Kinds of soil. — All farmers roughly classify their soils. A clayey soil they call heavy, and are careful not to work it when it is too wet. Otherwise it bakes and is unproductive. A sandy soil they call light. It requires abundant moisture, else the water leaches off and the roots cannot nourish the plant. The best soils are mixtures of clayey and sandy waste, and are called *loams*, which also are said to be light or heavy according to their character. As soils are of many kinds, it is fortunate that the needs of plants are also varied, so that some can thrive where others would perish. Swamp soils are often made available by drainage, and are of great value, especially for market gardening. Lime, potash, and phosphates are among the soil elements that plants use most, although they make but a small portion of the entire soil. Hence they may become exhausted, and the prudent farmer *rotates* his crops and adds fertilizers, to keep up a due supply of these materials.

The use of soil depends on climate. — Wheat thrives in the western provinces of Canada, corn in Illinois, and cotton in Mississippi. The soils are not indeed the same, but the principal difference is in the climate, which makes soils useful for certain crops. In the western part of the Great Plains, and in the valleys farther west, there is sometimes so little rain that our food plants do not thrive, but wherever the needed water can be supplied by irrigation good crops may be raised. There is no reason to doubt that the soils of northern Siberia are as

rich as those of southern Europe, but the temperature is hostile to agriculture.

Soils of Canada. — The character of soils depends on the forces which have made them. As we have seen, those of southern Ontario are largely transported soils. Near the shore of Lake Erie and in the hills north of Whitby and Cobourg they are sandy. North of Toronto and in many other places they are clayey. These conditions will be better understood after the study of glaciers. South of the ice limit, as in Virginia and Kentucky, the soil is made of the local rocks, and is clayey, sandy, and rich or poor in lime and other elements, according to the nature of the bed-rocks and the character of the weathering. Much of the soil of the Gulf region of the United States is of alluvial or river-borne material. Around the borders of the Great Lakes are tracts of level land mantled over with lake muds, deposited when the waters stood at a higher level. Thus every soil has a history, and its origin is in some way related to the changes by which the lands have come to their present condition.

Underground Changes in the Earth's Crust

Water in the rocks. — If a piece of common clay or a handful of soil is dried in an oven it will lose considerable weight, thus showing that a large amount of water was held among the mineral fragments. Samples of dry sand in Colorado have been found to absorb water to the extent of 29 per cent of their volume. If a boring be made, water will generally be found before great depths are reached. There is often an abundant supply within a few feet of the surface. Quicksand is only a fine sand so filled with water that its grains move with little friction, and it readily ingulfs man or beast that seeks to traverse it. All the deeper and solid rocks also contain water. No granite is so hard and compact that it does

not hold among its mineral particles a small percentage of water.

This water is nearly stationary in hard rocks which are not crossed by cracks. But where there are fissures, it circulates with more or less freedom. Through beds of sand, and particularly in layers of gravel, water will flow readily, though much more slowly than in a surface stream. The fact that water is present and moves in rocks leads to important changes.

Hardening of rocks. — Ground-water, coming in contact with the minerals that make up the rocks, is able to take more or less of the substances into solution. Thus it may take up calcium carbonate, iron, and many other minerals; continuing its course through the rocks, it may afterwards deposit part of this dissolved matter among the particles and bind them more firmly together, as by a cement. In a large gravel-pit one may usually see projecting layers of gravel, whose pebbles and sand-grains have been thus bound together by an underground deposit of calcium carbonate.

Fig. 44. — A gold vein in northern Ontario.

Mineral veins. — Water laden with dissolved minerals often flows through a fissure, and deposits part of its burden on the walls, until the fissure is filled with mineral substances different from the adjoining rocks. On breaking the rock, this *vein*, as it is called, appears like a narrow or wide ribbon, whose colour depends on the mineral deposited. Many veins are of white quartz, and sometimes the quartz contains gold in particles often too small to be seen by the unaided eye. Much of

the gold of Nova Scotia and British Columbia occurs in veins of quartz or some other mineral, and, indeed, veins contain the most important deposits of the precious metals. The metals have been dissolved from the rocks in which their particles were scattered, and brought together by underground waters.

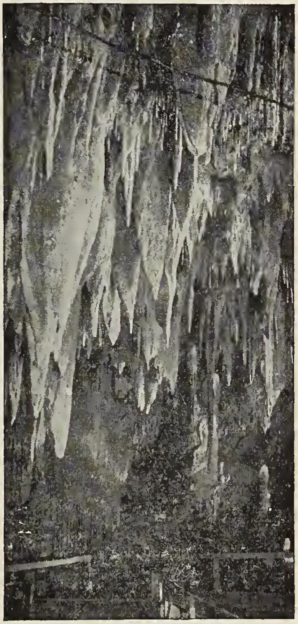


Fig. 45. — Stalactites, Luray Cavern, Virginia. Photograph by C. H. James. Copyrighted.

Caverns. — The Mammoth Cave in Kentucky consists of a complicated network of passages, having a total length of two hundred miles or more. It is entirely dug out of limestones. Water, which dissolves limestone more readily than most other rocks, filters along the joints and crevices, and gnaws incessantly until great openings result. The calcium carbonate is carried off by underground drainage to some point where the water joins a surface stream, and thence it goes out into the sea. Beds of gypsum and rock salt are dissolved even more rapidly, sometimes causing subsidence of the rocks above. A stream may flow for a considerable distance in a tunnel thus made. As the tunnel grows broader, its roof at length falls in, making an open ravine. If a small section of the roof remains in place, we have a bridge. Such is the origin

of the Natural Bridge of Virginia, over which a public highway passes.

Stalactites and stalagmites. — The water dripping from the roof of a cavern has soaked through the limestones above and brought out its load of calcium carbonate. Some of this is deposited at the point where the water comes out, and a mass like an icicle grows downwards. Where the drip is along a crack, the mass will be blade-shaped instead of needle-shaped. As it grows downwards it also increases in diameter by the addition of outer layers, like the rings of a tree. Such a formation is a *stalactite.* The dripping water strikes the floor of the cavern and there deposits more of its mineral burden, which thus builds a small mound called *stalagmite.* Sometimes the stalagmite forms a pavement over a considerable surface.

Caverns and living creatures. — Blind fishes and other curiously modified animals are found in caverns. Such changes have come about by successive generations of these creatures living in the cavern, where the eye, for example, from lack of light, has grown useless, or has disappeared. Many caverns in Europe were the refuge of prehistoric men and animals, whose bones are now found there, and the remains of ancient animals have been found in American caverns also.

Springs. — When water has soaked into the earthy mantle or the under rocks, and issues at the surface at a lower level, we call the outflow a *spring.* Coming out from a depth to which the warmth of summer does not penetrate, spring water is usually cool, and its temperature does not change from season to season. The size of a spring, like the size of a river, is related to the area from which the water is gathered. An underground river coming to the surface makes a spring of great volume. At Bellefonte, Pa., at several points in Florida, and at the source of the River Jordan, are such springs.

Mineral springs. — When the waters, on their way through the rocks, have taken a large amount of mineral in solution, this name is given to them, particularly if the waters have medicinal value, as by the presence of iron, lithium, sulphur, or other substances. Carlsbad and Vichy are well-known springs in Europe, and Saratoga is the most famous of the mineral spring localities of the United States. The Caledonia and Preston springs are examples in Ontario.

Fig. 46. — Cleopatra Springs and Terrace, Yellowstone National Park, Wyoming, U.S.A.

Hot springs. — Those of Banff in the Rocky Mountains, and Harrison, near Agassiz, in British Columbia, are the best examples in Canada. In such springs the waters have come up through heated rocks, and owe their temperature, either directly or indirectly, to the heat of the earth's interior. They are apt to be charged with minerals, because hot water dissolves the rocks more readily than cold water. Hence also the waters, losing their heat as they come forth, deposit minerals about the springs. Such abundant deposits form the well-known terraces about some of the springs of the Yellowstone region.

Geysers. — These are periodically eruptive springs found in the Yellowstone Park, in Iceland, and in New Zealand. At intervals of a few minutes, or a few hours, they spout a jet of water into the air, which plays like

Fig. 47.—Old Faithful Geyser, Yellowstone National Park, Wyoming, U.S.A.

a fountain for a few moments and subsides. The water is boiling hot, and is mingled with steam. The explanation is found in the fact that the boiling of water may be restrained by pressure. Deep in the geyser throat the water grows gradually hotter, but for a time does not change to steam, on account of the pressure on it of the water above. At last the heat so increases as to overcome the pressure, a great volume of steam is suddenly formed, and its expansion drives a quantity of the water into the air.

Wells. — The mantle of waste is usually filled with water except the uppermost part. This *ground-water,* as it is called, supplies ordinary springs, and is itself replenished by part of the rain which soaks in. When a boring reaches below the level of permanent ground-water, we call the opening a *well.* Water stands in it up to the ground-water level, and as this is pumped or drawn out the quantity is restored by oozing from the sides.

Artesian wells. — These are so named from the province of Artois in France. The principle of these wells is best shown in Fig. 48. The water soaks into a porous bed of

Fig. 48. — Ideal section of a valley, showing the principle of artesian wells. *A*, a porous rock; *B*, *C*, impervious rocks; *F*, height of the water-level in *A*; *D*, *E*, artesian wells, made where the ground is lower than *F*.

rock such as a sandstone. It is kept in this layer by fine-grained beds above and below, through which water does not readily pass. If now the beds all incline a little in one direction, there is a constant pressure on the lower waters of the porous bed. If a boring pierce the cover rocks, the waters will flow out, and sometimes spout to a considerable height. It is the same principle of hydraulic pressure that is used in making a fountain. This

general arrangement of porous and compact beds is fortunately found in many regions.

Water supply. — Here we count springs, wells of all kinds, rivers, and lakes, large and small. Large cities obtain their supplies from rivers and lakes, scattered houses from springs and wells. Unfortunately, not all water is wholesome, and much that is used is dangerous to health and life. As the rain soaks down to join the ground-water it may carry with it any filth that lies on or near the surface, and thus make springs and wells unfit to use. This is especially true in a village or thickly settled neighbourhood, but even the sewage of a single house may reach a well sunk in the yard. Every one should learn enough about the movements of ground-water to arouse caution in the use of wells, and every one should understand that water which is perfectly transparent and pleasant to the taste may at the same time be filled with the germs of typhoid fever and other diseases. River supply is dangerous if the up-stream region is thickly settled. Lake supplies are safe if due care be taken of the inflowing streams. Deep wells, such as the artesian, are likely to be safe. Increasing attention is given, as it should be, to this important subject, by cities and towns and by governments.

Landslips

Slips in railway cuts. — In the spring one may often see reports of blockades on railway lines because masses of earth have slid upon the track. The underground waters have lessened the coherence of the earth, and the steep slopes can no longer be maintained. Loose waste, as seen in talus slopes or heaps of sand, will rarely have a surface inclination of so much as 35° with a level plain. If this is exceeded in artificial slopes of earth, slips are sure to take place.

Hillside slips. — Small slips may often be found by the observant eye on the slopes of steep hills. Freezing and heaving of the material, followed by thorough soaking, cause it to fall away. On a larger scale slips take place where rivers undercut the valley sides, making an oversteep slope. In the early days a slide on the borders of the Genesee Valley in western New York carried down seventeen acres of land, and the hummocky surface caused by the lodging of the material is still to be seen along the valley bottom. Such slides are also of frequent occurrence along the banks of the Ottawa River.

Seashore slips. — In a similar way the waves of the sea undercut the shore lands, forming cliffs. A great slide of twelve acres in extent once occurred in this manner on the south shore of England.

Landslips in mountain regions. — Here the valleys are deep, the slopes are steep, the destructive forces are

Fig. 49. — The Cascades of the Columbia River. The central hill is a huge boulder. All the boulders of the view, together with the wooded hill at the left, are parts of landslips.

active, and everything favours the sliding of vast masses of earth and rock. In 1806 the upper rocks over a large area

of the south slope of the Rossberg in Switzerland slid suddenly into the valley, overwhelming the village of Goldau and causing the death of several hundreds of the inhabitants. Some years ago a portion of the mountain overlooking Frank, in Alberta, fell, causing great destruction of property and loss of life. Enormous masses of rock strewed the plains for miles around. The railway track runs over the fallen rocks.

CHAPTER V

WIND WORK

Importance of winds. — We are studying the forces that modify the crust of the earth and change the forms of the land; hence the physiographic effects of winds are those that now claim our attention. In the chapters on the atmosphere we shall consider the origin and kinds of winds, and their effects on climate as carriers of heat and moisture. The work of the ocean depends largely on the winds as wave-makers. The chapter on life will show how winds affect the grouping of many living things.

How dust is carried. — When very minute particles of earth are mingled with water, we call them *mud;* when they are dry and powdery, *dust.* The wind, which is only air in motion, picks them up just as moving water does, and carries them till the motion stops; then they settle slowly down. The wind does not blow hard in the woods, nor under thick bushes, nor even inside the leafy mesh of a meadow. It can pick up dust only from bare places, such as roads, freshly ploughed fields, and barren deserts. And when dust settles from the air, part of it gathers among trees and other plants where it is safe from the wind. So the air is a carrier of dust, just as water is a carrier of mud. It takes something from the ground where the ground is bare, and gives something to it where it is clothed with vegetation.

How sand is carried. — Sand grains are so much heavier than particles of dust that they cannot float in the air. When a strong wind drives them, they go rolling and bounding along, and are rarely raised more than a few feet.

Drifting sand often gathers in wave-like heaps or hills called *dunes*, and these hills are not stationary but travel in a curious way. As the wind blows across one of them its current is turned upwards so as to shoot over the crest, leaving a quiet spot, or eddy, beyond (Fig. 50). While it is rising, sand grains are dragging along with it, but a little beyond the crest they fall into the eddy and come to rest on the lee slope. Thus the wind always robs one side of the dune and gives to the other, and the position of the dune is changed (Fig. 51). As the dune progresses, a tree or even a house may be buried gradually, and afterwards reappear on the opposite side.

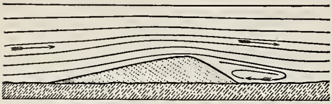


Fig. 50. — Profile of a dune, from back to front, showing its relation to the wind. The flow-lines of the air are drawn above, with the eddy in front of the dune.

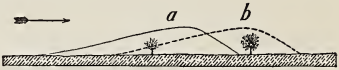


Fig. 51. — Diagram of the progress of a dune, from *a* to *b*. The arrow flies with the wind. A live tree standing before the dune when it is at *a* will be buried by the advance to *b*. Another tree, previously killed and still covered by the dune, will be brought to light when it has reached *b*.

Places where sand drifts. — Forests, thickets, and meadows protect sand as well as dust. So dunes flourish only on barren lands. Deserts are their chief haunts, but they find starting-points along coasts, where waves have washed up beach sands; along rivers, where sandy bars are dried in summer; and in a few places where the mantle of waste is so pure a sand that plants get but feeble hold on the land.

Flying Dust and Drifting Sands in Dry Regions

The western United States. — The plateau regions west of Missouri and Iowa are nearly everywhere subject to great dust storms. The climate is dry, the covering of

vegetation scanty, and winds sweep freely for hundreds of miles. The surface earth is picked up and carried in blinding storms. Thirty-eight such storms were reported during the years 1894 and 1895, and these take no account of the drifting by every considerable breeze.

Northern Africa. — The Sahara is not so completely a sandy desert as is often supposed. Less than one third of the Algerian Sahara is said to be covered with drifting sand. Rocky areas are not uncommon, and salt marshes, with numerous fertile oases. But, as a whole, the climate is dry, and the winds sweep the sand over wide areas. On the east the Nile Valley receives its contribution by the winds, so that the sands of the desert mingle with the sediment of the Nile floods.

Fig. 52. — A patch of grass on a field of loose sand. Drifting sand-grains lodge among the grass, and a hillock is built.

Asia. — With little interruption the sandy and half-desert tract extends from northern Africa far across Asia. Oriental explorers and travellers offer many vivid accounts of the desert storms. One of these, lasting a whole day, was encountered by Dean Stanley on the borders of the Red Sea. "Imagine all distant objects entirely lost to view — the sheets of sand fleeting along the surface of the desert like streams of water; the whole air filled, though invisibly, with a tempest of sand driving in your face like

sleet." Then follows an account of the difficulties of the caravan, the Bedouins covering their heads with their shawls, and the camels patiently facing the blast.

In central China vast areas are covered, sometimes to depths of hundreds, or even thousands of feet, by a yellowish earth which is believed to have been swept to its place mainly by winds. It is called *loess*, and is remarkably fine and uniform in character. Streams and even vehicles cut deep gorges into it, and it is so dry that in the bluffs, houses or dugouts are excavated in which many Chinese farmers live.

Drifting Sand on the Shores of Lakes and the Sea

The Great Lakes. — Approaching Chicago by one of the railways from the east along the shore of Lake Michigan, one sees sands in a belt of hills scantily clad with trees. Along the eastern shore of the lake are many dunes, some having a height of two hundred feet; and belts of great dunes are found on the borders of Lake Superior.

Western Europe. — On the coast of Gascony the belt of sand-hills is so continuous that at only two points in a distance of a hundred miles can the streams find their way out into the sea. The dunes on the coast of Holland cover a belt of land sometimes five miles wide. The hills are usually fifty to sixty feet high, but sometimes rise to more than two hundred feet. Dunes have been formed on the shores of Norfolk and Cornwall, England, and on some shores of Scotland and Ireland.

Dunes of the Mediterranean. — Many travellers have described the belt of sand-hills along the borders of the ancient Philistia. Ancient cities have been covered, and fields and orchards are often invaded at the present time. The strip of coastal land affected is from one to four miles wide. "It is a pitiful sight," says Geikie, "to notice olive and fig trees half-buried, their owners striving hard, season

after season, to shovel away the sand from their trunks, till they stand, in some cases, almost in pits which would close over them if the efforts to save them were intermitted even for a short time."

How encroaching sands are held in check. — Various methods are used. The French bring about the formation of a shore ridge of sand to a height over which the sands will not blow. This is accomplished by artificial barricades, rising in height from time to time, for a period of years. The principle is similar to that used in making fences to stop the drifting snows at a certain line. Another method is to plant grass or trees on the dunes. Common oleanders are used for this purpose in Bermuda. Grasses have thus been used to defend the coasts of Massachusetts, France, Holland, and Denmark. Where no precaution is taken, a dune has been known to migrate as much as seventy feet in one year. On the coast of Germany, a church which had been covered for thirty years by sand, was recently uncovered by the migration of the dune.

Fig. 53. — Planting grass to stop the drifting of sand.

The sand blast. — Sand driven by powerful currents of air is used in the arts for many purposes. Patterns are cut on glass, and heavy plate glass is readily pierced by such means. The blast is used for bringing out the grain of wood, for giving a granular surface to iron and steel, for carving inscriptions on stone, for lithographic drawing, for cleansing the inner face of tanks from foreign deposits, and for refacing grindstones and emery-wheels.

Sand blown by natural winds does similar work, and this natural sand blast suggested its use by man. Wherever the wind habitually drives sand upon boulders or ledges, wearing will result. But it is only in dry regions that such work is important, and many examples of it have been found in the western United States and the Sahara Desert. The student should not, however, suppose that this work is to be compared in importance with that of weathering, or streams or glaciers.

CHAPTER VI

GLACIERS AND THEIR WORK

Mountain Glaciers

The Gorner Glacier. — Monte Rosa is one of the highest peaks of the Alps. West of it are Lyskamm, Breithorn, and the Matterhorn. All these mountains rise to about 15,000 feet above the sea, and are the highest points of a lofty ridge which marks the boundary of Switzerland and Italy. North of this ridge a deep valley runs from east to west, and in this valley is the Gorner Glacier. We shall study this glacier with care, not because it is the largest even of the Swiss ice streams, but because it shows the characters of a glacier in an instructive way, and because the features described belong more or less to all glaciers.

The Gorner Glacier fills the valley to a depth of many hundred feet, and flows from east to west. It is known at its lower or north-west end as the Boden Glacier. At its eastern end, covering the high slopes north of Monte Rosa, are great fields of snow. This snow, accumulating from year to year and from century to century, packs together, pushes down the mountain slopes, and within a short distance becomes solid ice, which, at the rate of a few inches or feet a day, flows westwards down the valley. The whole length of snow-field and the glacier proper is nine miles. The upper edge of the snow-field is nearly 15,000 feet, and the lower end of the glacier is about 6000 feet above the sea.

The glacier is not entirely formed from the snows at

Monte Rosa. Lyskamm. Twins. Breithorn.

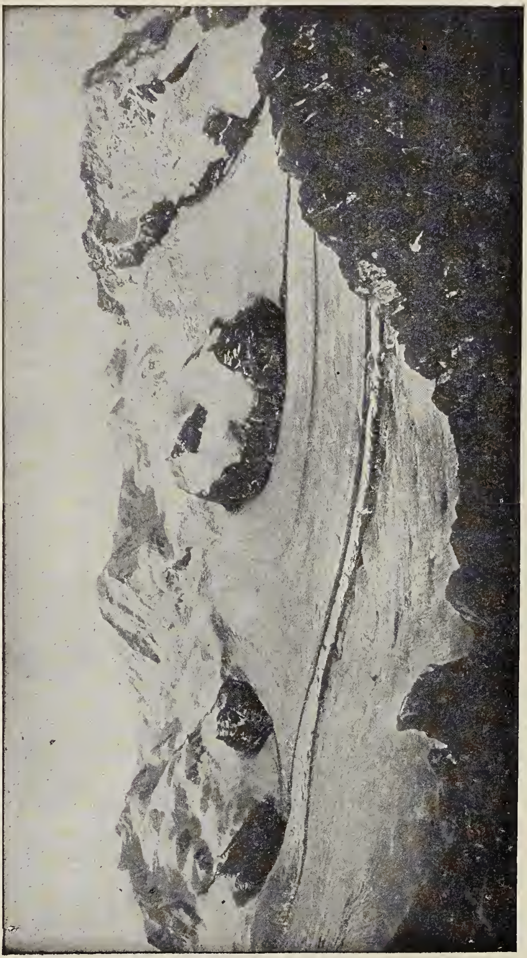


Fig. 54. — The Gorner Glacier. Switzerland, as seen from the Gornergrat.

its eastern end. Other snows gather on the north slopes of the ridge already described. These form several smaller glaciers which join the Gorner Glacier on the south and swell its size. These, beginning at the east, are: the Monte Rosa, Grenz, Twin, Schwarze, Breithorn, Little Matterhorn, and Theodul glaciers. From the ice and snows rise craggy ridges and peaks, which all together form one of the most splendid views to be found in any land.

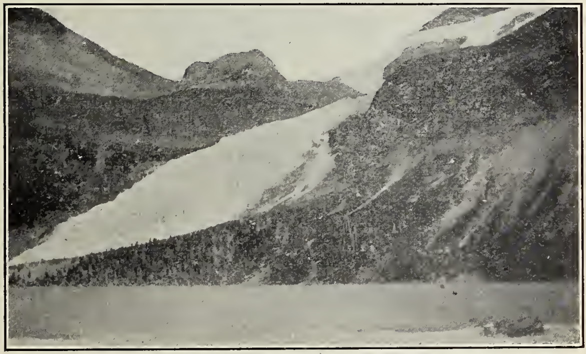


FIG. 55.—The Blue Glacier, Mount Robson.

As the glacier crowds the mountain side, it plucks away soil and rock. Other waste rolls down the steep slope and lodges on the edge of the stream of ice. Such a line of waste on the side of the glacier is a *lateral moraine*. When two glaciers unite, the left lateral moraine of the one and the right lateral moraine of the other join together, and a ridge or tract of waste stretches far down the trunk glacier; this is called a *medial moraine*. Where the glacier is finally overcome by the melting of its ice at the lower end, in the warmer valley region, more waste is found. The stones carried

on the surface as medial moraines, and the stones and finer waste carried along in the bottom of the glacier, are lodged in confused heaps where the glacier ends, and make up the *terminal moraine.*

FIG. 56.—The glacier surface, Mount Robson.

Streams which come to an abrupt end may be seen flowing over the glacier. They are formed by the surface-melting of the ice, and plunge into wells which penetrate the glacier to great depths, or into equally deep cracks, or *crevasses,* which may cross the glacier for considerable distances. Where the ice passes over a step or sharp descent of its rocky floor, it is strained, and many crevasses are formed. Cracking and melting combined will often make a glacier surface so rough that it cannot be traversed. Many surface pools are also formed. It will be readily understood that the deep fissures, wells, pools, and surface streams vary much from time to time.

FIG. 57.—A moraine, Mount Robson.

Melting goes on also within and at the bottom of the

ice. All these waters gather into a subglacial stream which is often a considerable river, and flows into the open air at the lower end of the glacier. This stream under the glacier wears the rocks like any other stream. It also receives much rock-flour made by the heavy grinding of the ice, and has a milky-white appearance, which it retains for many miles in the open valley. The Swiss call such water *glacier milk.* When firm rocks are ground up, the powder is usually white, but the powder from weathering is yellowed by iron oxide.

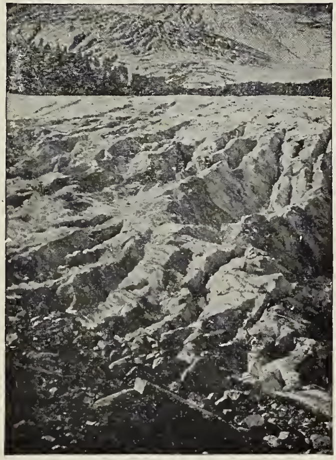


Fig. 58. — Crevasses.

The lower end of the glacier, sometimes for a term of years, pushes farther and farther down the valley; and it has thus destroyed cottages which were built too near its foot. The cause of such fluctuations is not well understood, but we can see that any change of climate which brought more snow, or less heat for melting, would make the glacier deeper, and cause the ice to push into the valley with more vigour.

Other Alpine glaciers. — Switzerland alone, not including the Austrian Alps, has several hundred glaciers. Of these, 138 are more than 5 miles long. The Aletsch, 15 miles long, is the greatest. The Lower Aar, 10 miles long, was made famous by the studies of Louis Agassiz,

the Swiss scientist, who was also the first to recognize the traces of ancient glaciers in North America. The Rhone Glacier, the source of the Rhone River, has a wonderful fall, or cascade, 1600 feet high. At the brink the ice is rent by innumerable crevasses, but at the foot it is welded again into a compact, smooth body.

Mountain glaciers of other lands. — In Europe these are found in the Pyrenees and Caucasus, and in Norway. In the last country they often descend from the uplands and enter the sea at the head of the sunken valleys, or *fiords,* which abound on that coast. In Switzerland no glacier reaches a point less than 3000 feet above sea-level. In Norway, as in Spitzbergen, Greenland, and other northern lands, the lowlands are not warm enough to prevent the descent of the ice-streams to the sea. In the Himalayas much longer and larger glaciers occur than are found in Europe, though less is known and written about them. Many glaciers occupy the high valleys and slopes of the Andes in South America and of the mountains of New Zealand. In Patagonia they descend to the sea.

Mountain glaciers of Canada. — The Rocky Mountains, Selkirks, and Coast Range of western Canada contain thousands of small and large glaciers, but very few of them have been studied carefully. The best known is the Asulkan glacier in the Selkirks, about a mile from Glacier station on the Canadian Pacific Railway. The snow-field which feeds this glacier sends down several tongues of ice in other directions. The largest ice-field south of Alaska is the Columbia field occupying a group of high mountains at the head waters of the Saskatchewan and Athabaska rivers. It covers 200 square miles and sends a number of fine glaciers into the valleys.

Alaskan glaciers. — Going northwards to Alaska, we find the ice-streams still larger, and, like those of Norway and Patagonia, they often flow down to the sea.

One of the greater of these ice-streams is the Muir Glacier. It lies near the head of Glacier Bay, from whose waters its cliffs of gleaming white rise to a height of 200 feet. Its thickness is 900 feet, so that much lies below the water surface. From the cliffs, masses crack off at intervals and float down the waters of the bay as small icebergs. At least nine ice-streams, flowing from interior valleys, come together in a broader valley or basin to form the trunk glacier. This glacier was first visited, in 1794, by Vancouver, who found it much larger than it is now. It was joined with glaciers from other sides of the bay and for 50 miles the sea was displaced by a solid mass of ice. Of the great *retreat*, the fifth part has occurred since the view in Fig. 59 was taken, the change being quickened by the rending effect of an earthquake in September, 1899.

Fig. 59.—The Muir Glacier, Alaska, in 1899.

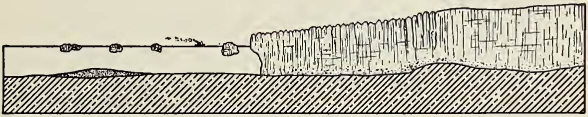


Fig. 60.—Section of end of Muir Glacier and part of Glacier Bay, showing icebergs. Scale, 1 inch = 3,500 feet.

On the southern slopes, and in the deep valleys of the range culminating in Mount St. Elias, are several large

glaciers. These unite on the narrow plain that separates the mountains from the sea, and form a glacier 30 miles wide and extending 70 miles along the base of the range. At some points the sea is reached, and at others a narrow strip of land lies between the glacier and the shore. Thus we have mountain glaciers at the sources, but a *piedmont* (foot of the mountain) glacier below. This lower ice-field is called the Malaspina Glacier. Its inner part, towards the mountains, is clear, but the outer border, for a width of several miles, is covered with rocks and earth brought in the ice and exposed as the ice melts. On parts of the overlying earth thick forests are growing.

Continental Glaciers

These are more often called *ice-sheets*, because they spread widely over the land, concealing its hills and valleys. The ice-sheets that now exist are instructive, because they prove the possibility of such gatherings of ice in former times, and because they throw light on the behaviour and appearance of the ancient continental glaciers.

Greenland ice-sheet. — The larger part of this great northern land is covered with a sheet of moving ice. The ice-fields are about 1300 miles long from north to south, and from 300 to 600 miles wide. Much of the border of the island is free from ice, especially towards the south, and along this narrow rim of land are the humble villages of the people, who live by fishing and the hunting of seals and walruses. In the interior the surface of the ice-cap, as it is often called, is several thousand feet above sea-level, and is an even plain. Thence it slopes gently down towards the edge of the land, where it pours out through valleys and stretches of lower ground to the sea-border. Some of the ice

streams which thus drain off the great central mass are very broad; the Humboldt Glacier enters the sea with a width of about 50 miles. We thus see that whatever may be the shape of the land in the interior of Greenland, all is shrouded from view by this perpetual mantle of frozen water. Nansen crossed the ice of Greenland, from sea to sea, in 1888. In later years, Peary traversed the ice-fields of northern Greenland, and determined the limits of the island towards the pole.

Fig. 61. — An iceberg near the Labrador coast.

There is also an ice-sheet, though much smaller than that of Greenland, in Baffinland, the great island north of Hudson Strait.

Icebergs. — When a Greenland glacier, several hundred feet thick, enters water deep enough to buoy it up, great masses separate from the frontal part and float away. These are carried southwards by ocean currents, often as far as the temperate latitudes, where their fleets put in jeopardy the summer navigation of the North Atlantic. The danger comes at the summer season, because until the late spring the northern waters are locked

in ice which has formed over their surfaces during the winter, and the fragments of the glacier can get no release. The thinner ice formed by the freezing of sea-water, and afterwards drifting with wind and current, is called *floe-ice.* Even this travels far down into the open sea. The *Polaris* party of about twenty persons, who found themselves adrift on a floe in October, 1872, were picked up in April, 1873, having drifted for a distance of 2000 miles.

Antarctic ice-fields. — A sheet of ice much larger than that of Greenland is believed to occupy the lands surrounding the South Pole. The interior has never but once been explored to any great distance, though expeditions sent out from England, Scotland, Sweden, and Germany have recently returned from its wastes of snow, adding to our knowledge of its mountains and glaciers. On January 9, 1909, however, Captain Shackleton, a British explorer, reached a point 111 statute miles from the South Pole, having crossed vast stretches of the southern ice and having discovered important mountain ranges. The interior is still the largest unexplored area yet remaining on the earth's surface. Along much of its shore precipitous ice cliffs rise from 100 to 200 feet out of comparatively deep water.

Fig. 62. — Face of the Great Glacier, Glacier, B.C.

Conditions necessary for the formation of glaciers. — The Rocky Mountains are higher and colder than the Selkirks, but their glaciers are fewer and smaller. The difference is due to the abundant moisture and heavy snows of the Pacific belt and the greater dryness of the mountains far from the sea. There is a similar contrast between the Yukon Territory and the Alaskan coast. There are no glaciers upon the mainland of north-eastern North America, while Greenland is nearly covered with ice. Greenland is no colder, but has more abundant snows. The Alps lift their great ridges and peaks into high altitudes, and thus stop and cool the cloud moisture from the hot Mediterranean until it falls as snow. A cold climate and abundant snowfall are thus essential to the making of glaciers.

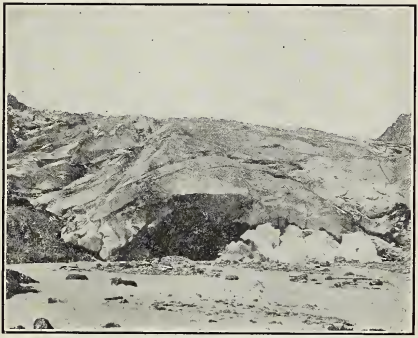


FIG. 63. — Cave in Yoho Glacier, near Field, B.C.

The glacier's work. — We have seen that a glacier tears away rocky material and carries it to considerable distances. We shall offer no explanation of the motion of a substance so brittle as ice. This is a difficult question, and for discussions of it the student is referred to text-books of geology. But no one doubts that glaciers move, dig into the crust of the earth, and carry stones and finer waste a distance of a few or even of hundreds of miles. A moving, heavy body like a glacier grinds powerfully upon

its rocky floor, until its base becomes shod with stones. These stones held by the glacier are like tools, and they both tear up boulders of the bed-rock and grind rocky flour from its surfaces. In mountain valleys the slopes rise steeply above the glaciers, and much material falls on the surface. The rocks carried on and in the glacier or pushed at its base, lodge where the final melting takes place, forming moraines. The subglacial stream carries out large quantities of the finer waste. We shall later see how glaciers mould the land surface into various forms.

Fig. 64. — A boulder on the plain.

Summary. — A glacier is a mass of moving ice, in a valley or widely spreading over the land. It can be formed only in regions of considerable cold and large snowfall. At the present time glaciers in low latitudes are found only at considerable heights, while those of the polar regions often descend to the sea. They accomplish many changes upon the earth's surface by wearing the rocks, by stirring and changing the soils, and by depositing their loads in hills and sheets of land waste. Some of these changes we shall now study more fully.

Evidence of a Continental glacier in Canada and the United States. — The land waste and the land surfaces of Canada and the northern United States often resemble those found in a region of present glaciers. This is so

widely true as to show that great glaciers once covered the face of the country.

The drift. — If we examine almost any part of Canada we shall find the stones, the soils, and the subsoils often consisting of material different from the underlying bed-rock. Pebbles and cobblestones, small boulders and great ones, even to hundreds of tons in weight, are scattered over the surface or buried in the finer waste. Bed-rock like these loose stones may be found 10, 20, 50, or even some hundreds of miles away. In a given place, all the boulders have come in about the same direction from the parent ledges. In Quebec the stones have travelled south-east or south. In Ontario the direction is south or south-west. These are *erratic* or strayed boulders, once moved by a glacier, as the Malaspina Glacier is now carrying stones from Mount St. Elias to the sea border. Many of the stones, however, are like the rocks below, and these have been carried only a short distance.

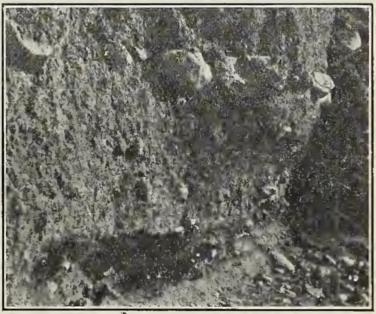


Fig. 65. — Boulder pavement in till, Parkdale.

It was formerly thought that these stones were brought over the lands by a great flood. But no explanation could be given of the origin of such a flood, and the fact was quite overlooked that the boulders commonly lie in finer, clayey waste, in which coarse and fine are mixed without order. If the mass had been deposited by water, it would have been sorted into coarser and finer layers, as is always

the case with such deposits. Such a formation of clay and stones packed in without sorting or order, known as *till* or *boulder clay*, is one of the best proofs that the region where it is found has been covered by a glacier. The ice moves slowly and heavily over the country, ploughs and grinds the bed-rocks, and mixes rock waste of various sizes and from various sources.

There is another element in the *drift*. A glacier is always melting; and the water that pours from top to

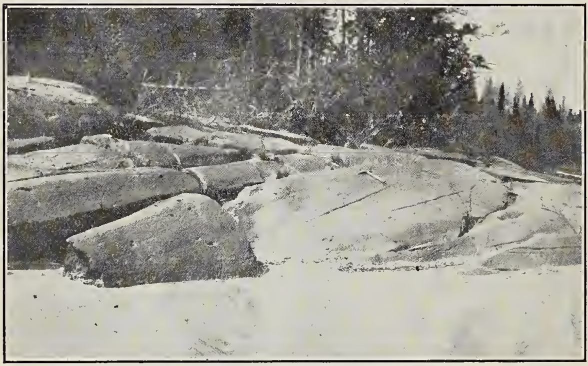


FIG. 66. — An ice-grooved surface.

bottom of the ice, or that flows under the ice and out from its front, carries clay, sand, and pebbles, that are laid down in beds or strata. Thus we have the stratified, or, as it is often called, the *washed* drift.

Glacial scratches. — Many of the boulders and pebbles of the till are found to be *glaciated*, or marked with parallel scratches. Often they look as if engraved with a sharp needle. Sometimes the scratches are deep and rough. A marked polish is seen on some stones. If we dig through the subsoil to the bed-rock, we shall often find the latter

scratched in the same way, or even deeply grooved and carved into flutings and mouldings. The glacier, shod with stones at its base, drags these over the bed-rock, and thus both the moving fragments and the floor over which they move are polished and graven.

The direction of the scratches corresponds to that in which the erratic boulders have been moved, and so, putting these and other facts together, we have full proof that glaciers have done the work.

Surface Forms due to Glaciers

Kames. — At Drummondville, at Sudbury, at Bird's Hill near Winnipeg, and at many other points in Canada are found clusters of sand and gravel hills. Sometimes they are high and have steep sides. If we dig into

Fig. 67. — Kames.

them we find irregular layers, generally of sand, gravel, or of coarse stones. Excavations for building and road materials are common. Cemeteries are often placed upon such hills, because they are always perfectly drained.

Such hills are called *kames*, a Scottish term (Fig. 67). Similar hills are now being formed at the wasting edge of the Muir Glacier.

Eskers. — Long, narrow ridges of sand and gravel are sometimes found. Often they are winding, and the same ridge may be 20 feet high in one place and 50 feet or more in another. They have steep sides, and are often bordered by swampy grounds. Roads are sometimes carried along their crests. Such ridges are found near Trenton,

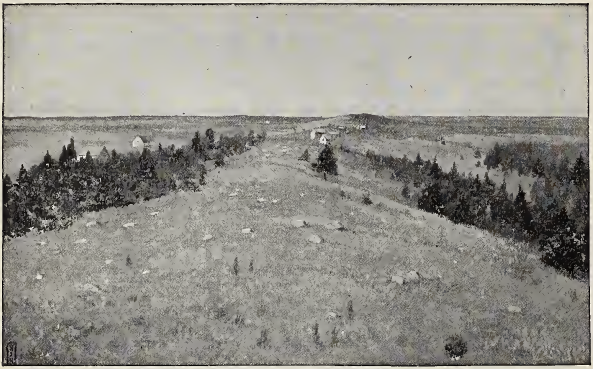


Fig. 68. — An esker.

near the western end of Lake Erie, and near Neepawa in Manitoba. They are called *eskers*, an Irish term, and are believed to have been made by streams flowing in tunnels under the ice (Fig. 68).

Drumlins. — Near Port Hope, along the Trent River, and west of Lake Winnipeg are many hills, made, not of sand or gravel, but of boulder clay; in shape either round, oval, or elongated, and everywhere smooth and outlined by simple curves. They are called *drumlins*, also an Irish term (Fig. 69); large numbers of such hills are found in

Ireland. They occur only in lands that have been modified by glaciers, and are believed to have been formed under the ice.

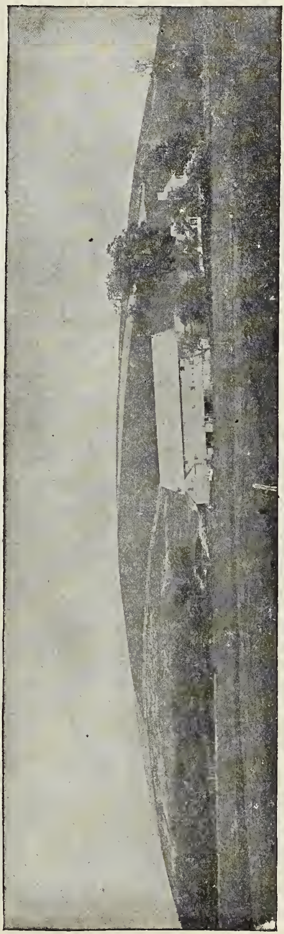


Fig. 69. — A drumlin.

Rounded and fluted rock hills. — If a region is marked by deep valleys and high hills, and a great glacier comes over it, the overriding and grinding of the ice will subdue the hilltops and hillsides, scour away frail ridges and sharp summits, and leave it a region of oval crests. Such hills are shaped like drumlins, but are often much higher and steeper, and, unlike the drumlins, consist of bed-rock, except the surface coating of boulder clay. They often show a somewhat fluted surface, the fluting being parallel with the longer axis of the elevation. The north-eastern summits of rocky hills in the Muskoka and Thousand Island regions are examples of glacial rounding and smoothing.

A similar change is wrought in valleys which have such position that the moving ice follows

them lengthwise. Projecting angles are pared away from their walls, and in time they become smooth-sided troughs with broadly curved bottoms. The walls of Lake Temiscaming and some channels of the St. Lawrence in the Thousand Islands were smoothed and straightened in this way.

Fig. 70. — Ice-rounded hills north of Lake Huron.

U-troughs. — Mountain glaciers also mould their valleys, giving them broad floors curving upwards at the sides so that the cross profile resembles a wide U. The U-*trough* is as characteristic of ice work as the V-gorge is of water work.

Fig. 71. — Gibbs Canyon, a U-trough of the Sierra Nevada. Compare with Fig. 72.

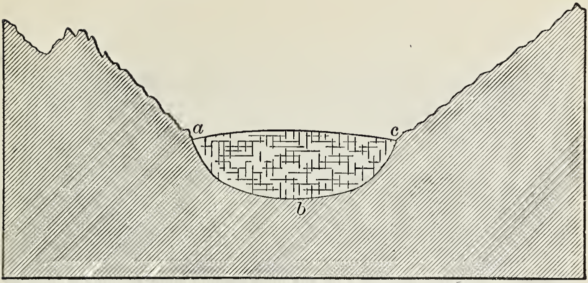


Fig. 72. — Cross-profile of Gibbs Canyon (Fig. 71), showing former glacier. *a b c* is the channel worn out by the glacier. After the glacier disappeared the channel was partly filled by waste from the slopes above *a* and *c*. Scale, 1 inch = 1,800 feet.

Giant kettles. — We have seen how the plunging and swirling water of a river drills holes in the rock. Pot-holes are also drilled by the streams which drop through wells from the top to the bottom of a glacier. Falling hundreds of feet, the streams acquire great force and are able to excavate pits of astonishing size. At Half Moon Bay near Gananoque, at Rockwood, and near Gravenhurst there are pot-holes of all sizes from a foot or two in width to more than 20 feet.

Fig. 73. — Pot-holes drilled in granite under an ancient glacier; Sierra Nevada.

Lake basins. — The innumerable lakes of northern Ontario and other parts of Canada are almost without exception due to glacial action in some form. Glaciers are so heavy and move with such power, that they will

scoop out basins in the solid rock. The lake shown in Fig. 74 lies in a bowl thus hollowed out by glaciers, as also

Fig. 74. — Lake basin hollowed from the rock by a glacier; Sierra Nevada.

do some of the Alpine lakes, and many lakes in the highlands of Canada. Even the Great Lakes of the St. Lawrence system are believed to owe part of their depth to excavation by the great ice-sheet.

CHAPTER VII

PLAINS

All continents are composed in part of low and comparatively level ground, and in part of hills and mountains. No sharp lines of separation can be drawn, but this will be best understood as we study special cases.

Marine and Coastal Plains

The plain of eastern Ontario and Quebec. — There is a low flat country between the Ottawa and the St. Lawrence and continuing through Quebec to tide water, with

Fig. 75. — The Iroquois plain at Port Credit, Ontario.

a gentle slope riverwards and seawards. Similar plains are found in places along the coasts of New Brunswick

and Nova Scotia, and near Vancouver on the Pacific Coast. If we dig below the surface, we find beds of sand, gravel, and clay, not yet bound into firm rock. In these uncemented rocks are shells and other animal remains, which closely resemble those gathering on the bottom of the sea at the present time. Except that it is exposed to the air, has some coating of soil and plants, and has been slightly roughened by streams, it is like a sea-bottom, and hence we conclude that not long ago in the history of the earth it was a sea-bottom. New land of this kind we call a *marine plain*, and where along the edge of the sea, a *coastal plain*.

Siberian marine plain. — The largest plain in the world forms the north and west portion of Siberia. It is difficult to appreciate the size of Siberia as a whole. It may be said that if Canada were spread out upon it, enough land would be left to hold all Europe, save Russia, with a space larger than the German Empire yet to spare. North-western Siberia, to a width of 1000 miles or more, is a smooth plain sloping imperceptibly northwards to the borders of the Arctic Ocean. As the rivers flow northwards, their lower courses are often bound in ice while their upper parts are open, and this leads to ice-jams and great flooding of the plains. The divides between the streams are ill-defined and variable. Shallow lakes and quaking marshes are of large extent. The water from the marshes between the Obi and Yenisei flows sometimes to one river and sometimes to the other, according to the direction of the wind. From about the sixty-ninth parallel northwards the plain is a *tundra*, or frozen prairie. The cold of winter lasts longer there than the warmth of summer, and controls the condition of the ground. To a great and unknown depth the subsoil is forever frozen; but in the brief summer the snows melt away and a few inches or a few feet of the soils are unlocked by the sun. Grass, mosses, swamp plants, and stunted berry bushes

grow rapidly, and this scanty vegetation, with fish from the rivers, supports the scattered and miserable population of this cheerless region. A few reindeer constitute riches, and these, for two-thirds of the year, live by pawing the snow cover from the mosses of the plain.

The tundra of Siberia has half the area of Canada. It gradually passes into a vast forest zone lying between the sixtieth and sixty-ninth parallels. Much of the timber is already exhausted, but the hunting of fur-bearing animals is an important industry. The forest belt is temperate in climate, as is a narrow but important zone of good agricultural land lying to the south of it. The latter is also rich in minerals. In western Siberia the plains cross all the zones now described, and embrace the hot, dry region about the Aral and Caspian seas.

This vast plain is marine, and young. Not long ago, as geologists count time, it was sea-bottom, and by gentle elevation of north-western Asia it has become land. Its surface parts indeed have been somewhat modified. Rivers wandering over its northern floors have spread land waste. The peaty accumulations of swamps have gathered upon it, and in the dry regions of the south the winds have worked over the surface materials. But below the thin sheets of later deposits the beds are marine, and the land has never been far above the sea-level. A similar plain is found near the mouth of the Mackenzie River.

Lake Plains

The Red River Valley.—The Red River forms the boundary of Minnesota and North Dakota, and flows thence through Manitoba to Lake Winnipeg. The stream meanders in strong curves and has scarcely sunk its channel below the surface of the land, which is so flat that one may travel for miles without rising or descending through a vertical interval of 20 feet. Thus the valley, so called, is a

smooth plain, sloping faintly towards the river. The soils are everywhere fine and rich, and bed-rock is rarely to be found. The fields are readily tilled and produce enormous quantities of wheat, for which the region is famed. In the closing stages of the glacial period, a vast body of water, called *Lake Agassiz*, occupied this valley. When this lake was drained off by the removal of the glacier, its bottom became the *lake plain* we have described.

Fig. 76. — A plain in the Red River Valley.

The Great Lake plains. — The traveller by the Grand Trunk Railroad from Trenton to Hamilton and St. Catharines crosses flat ground bounded to the north by hills, as far as Hamilton, after which the hills are to the south. This flat level is the bottom of *Lake Iroquois*, the older Lake Ontario, when its outflow was through the Mohawk Valley. Whatever may have been the inequalities of the earlier surfaces, they are subdued and hidden by the covering of lake muds gained at the close of the glacial period. If we could drain Lake Ontario, its present bottom would form a similar but much larger plain.

Other lake plains. — We have now studied two illustrations of level lands of this kind — one in the East and one in the West. Though surface drainage has uncovered these plains, there are still large lakes remaining.

Very similar plains are found south of Georgian Bay, and between Lakes Erie and Huron. Wherever a swamp or meadow is found rimmed about with higher land, a lake has probably existed, and has disappeared by the filling of the basin with mud or the draining of its waters. Such small lake plains are numerous in all the region of the ancient ice-sheet, and they are often found in the high mountain valleys of the West.

River Plains

The alluvial plains of rivers and their deltas, great and small, must be classed here. We readily see that there is no sharp distinction between great river deltas and the adjacent coastal marine plains, as where the Mississippi delta merges into the other lowlands of the Gulf region. The rivers of Siberia, flooding wide districts of the marine plain which they cross, illustrate this coöperation of river and sea in shaping lowland surfaces; the central valley of California and the plain through which the Mackenzie River flows towards the Arctic Ocean are other examples.

Worn-down Plains

We have already given an account of the gradual wearing down of a river basin by the meandering of the streams and the weathering of the lands between. If such wasting were continued long enough a perfect plain would be produced. But as the slopes become gentle, the wasting becomes very slow, and it is not known that the work has ever been carried to completion. Because the worn-down plains are imperfect, they are sometimes called *pene-plains*, a word meaning "almost plains." A portion of the valley of the Hudson River, and the hilly plain of the Archæan region in northern Canada are good examples.

Plains of North America

The principles which have been explained by reference to a number of scattered regions may now be profitably applied to a short study of the lowlands of our own continent. Let us remember that North America is bordered on the west and east by great belts of mountain and plateau. Between these, from the Arctic Ocean to the Gulf of Mexico, runs a broad belt of lowland, rising moderately on the borders of Canada and the United States, and sloping gently up to the highlands east and west.

Coastal plains of the United States. — Along the whole Atlantic coast of the United States, a marine plain stretches between the Appalachian Mountains and the sea. It is continued beyond Georgia, forming the southern part of all the Gulf States, and passes through the Gulf lowlands of Texas and down the eastern side of Mexico, to the flat, hot plain between Vera Cruz and the mountains. Large parts of this plain north of the Gulf of Mexico are directly shaped by the Mississippi River, and covered by its flood-plain and delta deposits.

Prairie plains. — Much of the Mississippi basin is a worn-down plain, more or less covered with loose materials of various origin, some deposited by glaciers, some in lakes, and some by rivers. The plains are well enough watered to bear luxuriant native grasses and cultivated crops. They are trenched in a shallow way by many streams, and along these most of the native timber is found. The intervening lands may be rolling, but are never high, and are without forests. This is not because the soil will not produce them, for it is deep and fertile. The absence of forest has been ascribed to various causes, among others, to the fires kindled by Indians to maintain open pasturage for the herds of buffaloes. Temperate

climate, rich soils, absence of forests which must be laboriously cleared, easy tillage, good grades for railways — such are some of the conditions which made the settlement

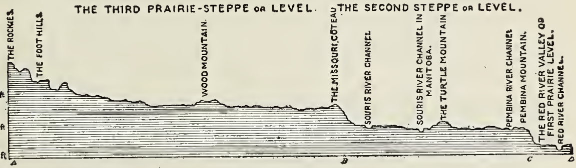


Fig. 77. — Profile of the three prairie levels at the boundary line between Canada and the United States.

of the prairie section so rapid, and its growth in wealth and population so surprising. The prairies often merge into the lake plains already described, and extend north-west to the forest region of the northern parts of Manitoba, Saskatchewan, and Alberta.

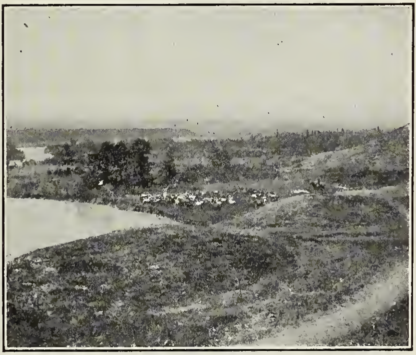


Fig. 78. — A plain on the Third Prairie Level, near Calgary.

In western Canada, the prairie region has a triangular shape, the edge of the forest-covered country running north-west from northern Manitoba about to Edmonton. The prairie is divided into three steppes, the lowest and most eastern being the Red River valley, rising from 700 to 800 feet above the sea. Beyond this comes a

range of hills running from the Pembina Mountain on the south, through the Brandon hills and the Riding and Duck mountains, to the Porcupine and Pasquia hills on the north side of Manitoba. These hills, which are often morainic, mark the beginning of the second steppe, which has an average elevation of 1600 feet. The third and largest steppe includes most of Alberta, with an elevation of 2000 feet on the east, rising to 4000 as the foothills of the Rocky Mountains are approached.

While these prairie steppes are well marked towards the south, the whole plain slopes downwards towards the north-east, so that in the latitude of Edmonton they can no longer be distinguished.

It will be noted that these vast surfaces are not all smooth plain, though large districts are nearly so. Some

Fig. 79. — An Eskimo camp on tne Barren Lands, near the Arctic Circle.

parts are very rough, and there are broad, hilly tracts rising 1000 feet or more above the general level. These are locally called mountains, though not deserving the

title when compared with the Rockies. In addition to the inequalities of the hills, the plains are often deeply furrowed, especially towards the west, by the valleys of rivers, the Saskatchewan and its tributaries, draining into Lake Winnipeg. There are also basins without outlets in Saskatchewan such as the Quill and Old Wives lakes, more or less salt or alkaline.

On the east of the prairies are the hills and ancient worn-down mountains of the Lake-of-the-Woods and Hudson Bay region. On the west rise the great mountains of the Cordilleran system. Wheat has been grown as high as latitude 58°, or opposite the middle portion of Hudson Bay. In the Arctic parts of the continent, the plains resemble those of Siberia, though less extensive and more broken by waters. These are commonly known as the *Barren Lands*, but in the short spring and summer season, they are covered with myriads of flowers, and insect life abounds. The far north and parts of the lower Yukon valley form a tundra.

Summary. — In this chapter certain important plain lands in different continents have been chosen in order to bring out the principles which explain them, and which will give us the key to other plains, like the vast, smooth lowlands of South America or Australia. The way in which a plain was made is one of the most instructive things that we can learn about it. We have seen that, with respect to origin, plains are of several classes: (1) marine plains, narrow or wide, which are sea-bottoms made bare by uplift; (2) lake bottoms, uncovered by the draining away or drying away of the water; (3) river lands, built of waste brought and spread by rivers; (4) worn-down plains, wrought out by the slow wasting of higher lands. We have also seen that a vast tract of plains, as in North America, can only be understood by using all of these principles. Still further, it has appeared that plains hav-

ing the same origin have different names (as tundra and prairie) because they have different climates. One region is temperate, another is frigid, and a third is hot; one is moist and another is dry, hence they differ in kind and abundance of plants and animal life. So, too, man himself is restricted, favoured, and variously modified.

CHAPTER VIII

MOUNTAINS AND PLATEAUS

Mountains are not an easy theme for elementary study; they are so great and so strange to many who have spent their lives on lowland plains. They are so varied, also, that no single definition can be a good one. We take up first the mountains of our own country, with the high plains, or plateaus, that are joined to them. Our purpose in this is to find the great principles concerning all mountains. We wish to be able to answer such questions as these: What is a mountain's form? How are mountains made? How are they related to the lower and smoother land? What is their history, and how do they pass from youth to age, or from high, sharp ridges and peaks to low, subdued hills? How do they affect the life of the earth?

The Rocky Mountains in Alberta. — As the traveller approaches the Bow Pass from the east, he sees rising before him a lofty mountain front, stretching far away to north-west and south-east. This is the eastern face of the Rocky Mountains. The plains cease, and the mountains begin at heights of 4000 or 4500 feet above the level of the sea. The highest peaks in sight reach about 12,000 feet. Snow is always seen, even in summer, on the upper slopes and in the high gorges of the outer range, and some of the more distant, higher peaks bear snow-fields and small glaciers. Part way up the Rocky Mountain slopes timber grows. The upper limit, at about 7500 feet, is called the *timber line*. It is not a sharp boundary, but a belt along

the slope, in which the trees become scattering and disappear. This may be taken as a definition of timber line for all mountains. Above this line for several thousand feet, to the top, unless when covered with snow, are crags and ledges of rock, mostly limestone and slate, and great slopes of angular, sharp-edged boulders riven from the mass of the mountain by frosts. The average slope is not very great, though there are cliffs too steep for trees to grow upon them.

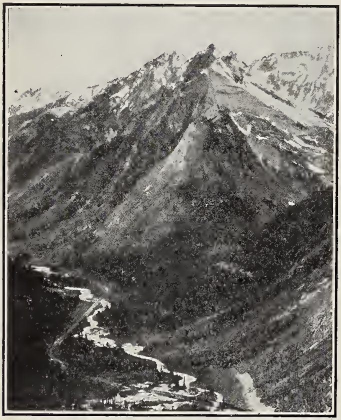


Fig. 80. — The Illecillewaet Valley and Mountains, near Glacier, B.C. Note the timber line.

The rains and melted snow from the well-watered mountains drain down to the dry plains through narrow valleys or deep canyons which they have worn out of the mountain's mass. Stretching out from the foot of the range on the east are sheets of sand and gravel. These are deposits made by the rivers and torrents of the past, cut into by the modern rivers, forming terraces. Through these deposits rise in many places the Foot Hills, which in eastern Canada would be called mountains.

Structure of the Rocky Mountains.—If we follow the Bow River into the Bow Pass, we find that the river has sawn its way through the uplifted rocks, showing their arrangement. On each side of the pass there are steep cliffs of stratified limestone and shale, lying in general nearly flat

but sometimes broken or bent. Under the limestone in some places one can see shale. Advancing along the

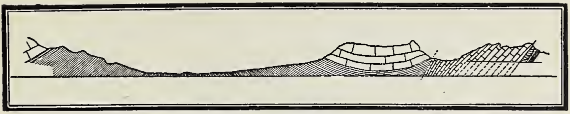


Fig. 81. — A section of the Bow Pass.

pass the rocks are tilted, crushed and pushed over each other by great thrusts which came from the west. Beyond Banff the stratified rocks have been built into great folds or arches, such a series of folds as is made by the wrinkling of a coat-sleeve. At Castle Mountain the beds have been bent into a gentle downward fold. Foldings of a similar kind reach from this to the steep slope towards the Columbia valley, here 2500 feet above the sea, and splendid mountains, such as Mt. Stephen, rise, like cathedral spires, 7000 feet above the Kicking Horse River, which flows to the Columbia.

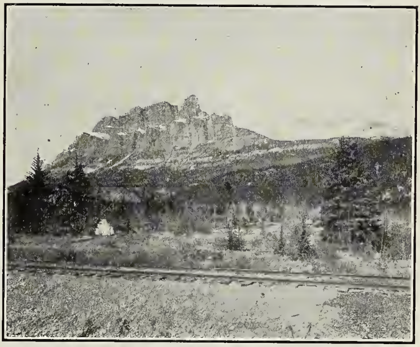


Fig. 82. — Castle Mountain, near Banff, Alberta.

The main range of the Rocky Mountains has much the same character south-east into Montana and north-west to the Athabaska Pass. There are along the north-east side parallel ridges with steep cliffs towards the plains,

and gentler slopes towards British Columbia. Near the middle of the range and to the west there are gentle folds carved by the rivers into varied forms.

Fig. 83. — Mount Stephen, near Field, B.C.

The Selkirk Mountains. — Inclosed by the great bend of the Columbia are the Selkirk Mountains, which are far older than the Rockies, and different in structure. Along each side of a central axis of ancient granite and gneiss there are old slaty rocks. These mountains are seldom more than 10,000 feet high, but have much larger snow fields and glaciers than the Rockies, since they are nearer the moist winds of the Pacific. The Selkirks are generally looked on as part of the Gold Ranges, which lie parallel to them to the west and extend far to the north. Gold has been mined in many places among these moun-

Fig. 84. — The Three Sisters, near Canmore, Alberta.

tains. Towards the south is the Kootenay region with the great gold and silver mines of Rossland and the Slocan. Lead and copper are produced there also.

All these mountains have been squeezed, folded, often crushed and uplifted. But crushing and uplifting tell only half the story. The lifting took place long ago, and a vast amount of rock has been worn away. Not only have the mountain ridges been reduced in height, but they have been carved into new shapes. Their gorges and spurs, cliffs and peaks, all the details that give character to their scenery, are the work of storm, stream, and glacier.

The Interior Plateau. — West of the Gold Ranges is a table-land formed of worn-down mountain structures, recently elevated again, so that the rivers are cutting canyons. This table-land is much drier than the plains along the Pacific Coast, since a range of mountains cuts it off from the moisture of the ocean; but it is not so dry as to be desert, like some parts of the much greater plateau region of the western United States. The plateau is 500 miles long and 100 wide, with an elevation of more than 4000 feet near the international boundary, and ending with less than 3000 towards the north-west. A similar but

Fig. 85. — Lake Louise, near Laggan, Alberta.

lower plateau runs from the north end of British Columbia northwards to the Yukon Basin, gradually sinking towards the Arctic Sea.

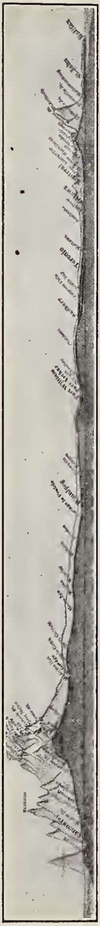


FIG. 86. — A section across North America, from Halifax to Vancouver, showing the relations of plains and mountains.

The Coast Range. — For 900 miles along the Pacific, the Coast Range of mountains rises boldly above the sea, cut by deep and narrow inlets or fiords. Though not very lofty in British Columbia these mountains bear many small glaciers, especially towards the north. When they pass into Alaska and the Yukon Territory they rise to greater heights, culminating in the loftiest peaks of North America, Mounts St. Elias, Logan, and McKinley, which rise from 17,000 to 20,000 feet above the sea.

General view of the western mountains. — This great system of mountains is made up of the Rockies, or Laramie range, the Gold Ranges, the Coast Range, and the partially submerged range of Vancouver and Queen Charlotte Islands. The belt, including the Interior Plateau, has a width of about 400 miles for the whole length of British Columbia. To the north the mountains spread out, the eastern range going on between the Yukon and Mackenzie rivers towards the Arctic Ocean, the others bending west into Alaska.

Southwards, too, the mountain region broadens in the western United States, inclosing great plateaus and basins, and passing through Mexico. The ranges run out or change into other forms with different names as we go to the far north or south, but all have a general north and south or

Fig. 87. — The mountains of British Columbia.

north-west and south-east direction. As a whole they are the Cordillera of North America. All western America is a region of mountainous foldings and uplifts of the earth's crust.

Mountains of eastern North America. — The main system of mountains in the East is the Appalachians, which extend from near the Gulf of Mexico to eastern Quebec and the Maritime Provinces. They are not all alike and they were not all made at one time. In general they are folded mountains like the western part of the Canadian Rockies, but the direction of the wrinkles is north-east and south-west. The wrinkling took place very long ago, and there has since been an enormous wasting of the rocks. Some rocks have wasted more than others, and the ridges which are left are not the original wrinkles, but the projecting edges of such rock beds as were best able to resist wasting influences.

The Laurentides. — The mountains of eastern Quebec, along the north shore of the St. Lawrence, are old and subdued. The highest of them hardly reach 4000 feet above the sea, and their rounded summits show only hard, crystalline rocks, such as granite and gneiss.

The highest mountains in eastern America are probably the Torngats in north-eastern Labrador, which rise to 6500 feet, or, according to some authorities, 8000 feet or more. They are of the same age as the Laurentides, and may be looked on as their northward extension, but very little is known of them.

Young, mature, and old mountains. — This is the history of mountains: First, ridges are uplifted; they may be wrinkles, or they may be blocks, broken loose and pushed upwards. In youth they are small, in maturity large, but the change is always slow. As they grow, storm, frost, and stream attack them; gorges furrow them from summit to base; spurs, sharp crests, and

peaks are carved out. Uplift strives to make the summits higher, wasting to make them lower. The mountains are now mature. When uplift ceases, wasting continues alone. Slowly through the ages the tops are lowered, and the rugged angles of vigorous middle life are replaced by the smooth curves of old age. The old summit lines are now lost, and new summit lines follow the harder rocks. Still more slowly these too fade away, and all that remains is a worn-down plain, with low, scattered hills — the second childhood of mountains.

Mountains of other lands. — We may describe the geography of mountains by comparing a few other examples with those of North America. The highlands of Scotland are like the Laurentides in being very old mountains, much subdued and of small height. Similar are the mountains of the English Lake District in the north of England, whose chief summits are little more than 3000 feet above sea-level. The mountains of the Scandinavian peninsula are also old and worn, though higher than those of Great Britain.

In the south of Europe, however, we find mature mountains, high and very rugged. In the Pyrenees and the Alps, the mountains have been squeezed, folded and broken, and forced upwards, so that they rise from twelve to nearly sixteen thousand feet above the sea. As they were not overridden by the ice of the glacial period, their peaks are unworn; and the gnawing of the modern glaciers, which flourish in alcoves under their summits, keeps their crests blade-like. Below the glaciers, torrents are powerful and busy, and in all the uplifted country are gorges and deep valleys. Sharp peaks, lofty and often vertical cliffs, and valleys strewn with the waste of the heights are the features of the land. Conspicuous in the scenery of the Alps are its separated peaks, springing from spurs

between gorges and standing free from the main crest-line. These are often named needles or horns, as in the Matterhorn, which means "stag-horn" (see Frontispiece). A line of peaks marks a ridge, a strand of ridges makes a chain, and several chains, as in western America, make up a mountain system. On the north of the eastern Alps is the Bavarian plateau, with a smooth surface about 2000 feet above the sea. Munich stands on this plateau near the northern foot of the mountains, and the Danube flows eastwards over it. It is related to the Alps as the Great Plains are to the Rocky Mountains.

In Asia, the highest mountains in the world, the Himalaya, are in middle life, like the Alps. Far up among their heights the rocks contain shells which originally grew in the sea. Along a belt running far east and west, the earth's crust was crumpled and broken and the mountains reared. Glaciers, deep valleys, and strong streams are common here as in the Alps. In both regions immense landslips occur, as ill-supported sides of the mountain fall off into the valleys. In both, also, snow comes down in the form of avalanches, overwhelming forests and destroying human life.

To the north is the plateau of central Asia. Its highest parts in Tibet are about 14,000 feet above the sea, or as high as our western mountain peaks. Hence the region is sometimes called the "Roof of the World." As our western plateau is broken by mountains, so is the plateau of central Asia, but its mountains and plains are on a grander scale. Gradually, on the north, plateau and mountains descend to the level of the Siberian plains. A vast continental rise of land, of which the rugged parts are mountains and the smoother, intervening parts are waste-floored plains — such is the character of the highlands of Asia, as of those of western America.

The Andes also are high and rugged mountains, and by

that fact, we are told that they are in the vigour of youth, or middle life. South America has less of plateau and more of low plain than the other great continents.

Earthquakes in mountain-making. — More will be said about earthquakes in the chapter on volcanoes. Any shock given to the firm rocks of the earth's crust causes vibration, and produces a shaking of objects at the earth's surface. In straining the crust enough to bend thick beds of rock, many sudden breaks and slips take place, which send shocks for long distances through the rocks. Many earthquakes are due to this cause.

Mineral products of mountain regions. — Coal is found near Banff and in the Crow's Nest Pass in the Rocky Mountains, but in many other places it is found also where the rocks are undisturbed. Coal is not therefore a result of mountain-building, though soft coal may be changed to anthracite by the crushing that goes with the rearing of mountains.

But many of the metals are found chiefly in mountain lands. It is there that they have been dissolved out of the rocks, often by heated waters, and deposited in mineral veins. Hence it is that in the Kootenay region of British Columbia there are valuable deposits of gold, silver, copper, and lead ores. The metallic wealth of the West is all in the mountain lands. In connection with the folding and crushing, the various ores have been formed by the slow deposition of dissolved matter in the crevices of the rocks. The iron and copper of Lake Superior are found in a region of ancient mountains now worn away.

When gold-bearing veins waste away, along with the general wasting of a mountain side, the gold is washed down-stream, and comes to rest along with gravel and sand wherever the progress of the waste is checked. Such gold-bearing gravels are known as *placer beds,* and

the washing of the gravels to separate the gold is known as *placer mining.*

Not all mountains contain mineral wealth. No gold or silver is mined in the Laurentides. The low mountains of Saxony have long been a mining centre, while the lofty Alps are poor in valuable minerals.

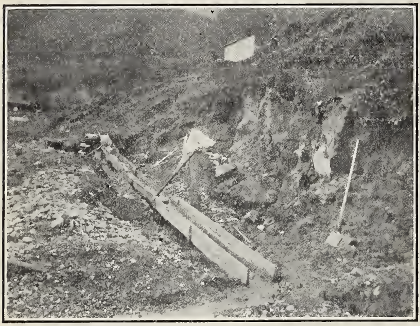


Fig. 88. — Placer mining in British Columbia.

Climate of mountains. — In ascending lofty mountains, one finds the same changes of climate in a few hours or days that would be met in a journey from tropical or temperate to arctic latitudes. This will be well understood by reviewing the belts of temperature and vegetation in the Alps. On the plains of northern Italy the olive flourishes, and in the deep valleys and along the lower slopes the vine abounds. As we ascend, we find first the broad-leaved forest trees to heights of 5000 to 5500 feet on the south slope, and 4000 feet on the north slopes. This brings out the fact that climate may differ much on two sides of a mountain range. The direct rays of the sun and the winds from the warm Mediterranean affect the south front of the Alps. Above the deciduous trees come the cone-bearing or evergreen forests. The coniferous trees are important in preventing floods and checking avalanches, as well as affording supplies of timber and firewood for the thrifty peasant.

Above the trees are the upper pastures, brilliant with flowers of every hue, to which the flocks and herds are driven only in the summer. Still above is the zone of rock and perpetual snows. Snows may wrap the highest summits, as Mont Blanc; while often the upper mountains are so steep for thousands of feet that the snows slide off and bare crags prevail. From base to summit of the Alps, one-fourth is tillable, one-half is forest and pasture, and the remaining fourth is utterly barren.

The climate of northern Italy is warm-temperate, and we thus range from this to polar climate as we ascend. If we rise, however, from the foot to the summit of the equatorial Andes, we there range from a tropical to a polar climate. In the far north and south there is less contrast, because ice and snow there prevail down to the level of the sea, as upon the slopes of Mount St. Elias. In Canada the Rocky Mountains present the same conditions as the Alps and are belted by zones of climate — cooler and moister above, and warmer and drier below.

In our eastern mountains the range of temperature is small, because the mountains are low. Still the summits are always cold at night, the mean temperature for the day is never high, and the winters are long and marked by heavy snows. In the United States the southern Appalachians carry a wedge of cooler climate far down between the hot Carolina coasts on the east and the half-tropical country along the lower Mississippi.

Life of mountain lands. — Some facts belonging to this subject have already been given. Thus we have seen how rapid is the change to colder climate and the corresponding plants as we rise towards the tops of high mountains; tillage of the soil is confined to the valleys and lower slopes, while grazing and timber industries run to the middle slopes or to the summits, according as the

mountains are in higher or lower latitudes, or are themselves of great or small altitude.

In the mountainous parts of Switzerland the peasants till the narrow valley bottoms, reclaim the rough surfaces of the torrent fans, and raise patches of grain and hay on the talus and other waste slopes. The dairy is a chief means of support, and men, women, and children join in all the industries of the field, while wood-carving and other small manufacturing occupy the winter months. Houses are built of wood, with wide-spreading cornices, the thatch sometimes weighted down with large stones. The splendid scenery of the Alps, close to many populous lands, has made Switzerland the "playground of Europe," and the entertainment of tourists may be called the chief industry of the mountain people.

In our Western mountains the conditions of human life are entirely different. The chief attraction in these mountains is the mining of the precious metals and the cutting of the timber. Instead of humble peasants, native to the soil for centuries, we find the most hardy and energetic types of American life in the absorbing search for mineral and forest wealth. Mining and lumber camps, which are in truth cities, spring into being, and as swiftly decay when the mines cease to be productive and the forests are denuded. The roadways have been built not often for the tourist, but almost without exception for the shipping of minerals and timber and the introduction of supplies. The keen, vigorous, and often rough life of our Western mountains is in strong contrast to the quiet and simplicity of Alpine regions. The causes are partly geographic and partly historical.[1]

Ancient and worn mountains make up much of the rugged surface of Wales. No precious metals occur, but

[1] Some of the valleys in our Western mountains are exceedingly fertile, and here grains and fruits are extensively grown.

the slate, found only in mountainous countries, furnishes, in its quarrying and shipping, an important industry, while in the south are deposits of coal, leading to mining and manufacture. Similar are the low mountains of the English Lake District. Here, however, there are no important minerals, but lakes, mountains, and beautiful valleys, made memorable as the homes of Wordsworth and other men of letters, the whole region being chiefly a summer refuge for toilers from the cities.

The Scottish Highlands, with their thin, cold soils and stretches of bare rock, their rough stone cabins and unchanging poverty, under the leaden skies of the north, show us still another type of the life of mountain lands. No great cities, diligent but small tillage of the soil, isolation and primitive ways — such is the life of mountains, save where the rocks yield coveted treasure. There modern life pours in like a tide, and the virtues and vices of the latest civilization are seen to the full.

Barriers and passes. — Because most mountains are in the form of long belts of folding and uplift, they serve to separate the lands on their opposite sides. Thus the Rocky Mountains, in Canada, form a strong and almost continuous wall between the Great Plains and the Pacific slope. It is partially cut by the valleys of the Bow River towards the east and the Kicking Horse River towards the west, where the Canadian Pacific Railway has found a passage at 5300 feet. Before reaching the final westward slope towards the Pacific, a descent is made to the Columbia, at 2500 feet, and the Selkirks are crossed by Rogers' Pass, 4300 feet above the sea. There are, however, lower passes through the Rockies, to the south at the Crow's Nest (4427), and to the north at the Yellow Head and Peace River passes. It is through the Yellow Head Pass that the Grand Trunk Pacific Railway purposes to reach the Pacific. The passes through the Rocky Moun-

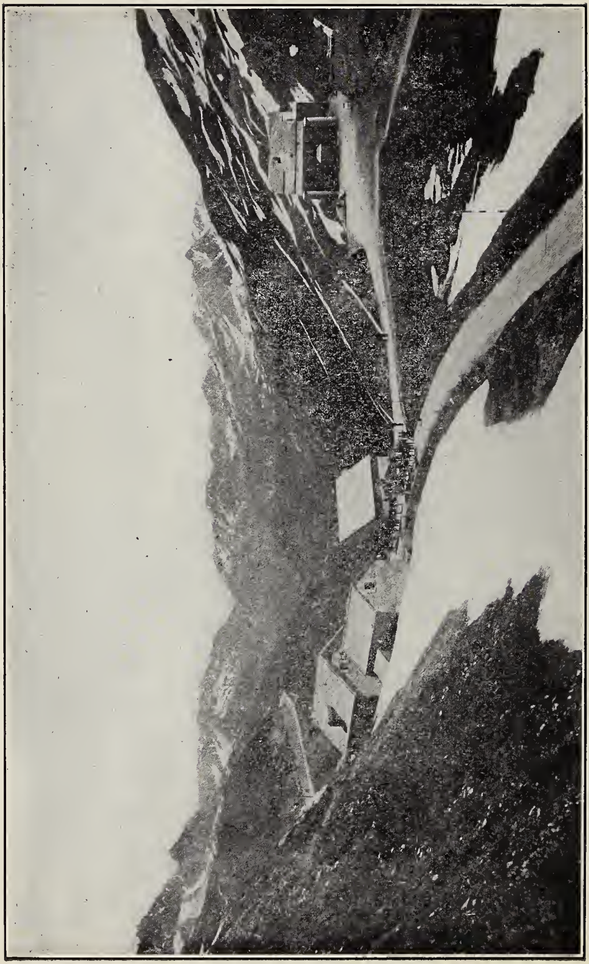


Fig. 89. — The Furka Pass. Summit station on a carriage road crossing the Alps from the Rhone Basin to the Rhine Basin.

tains in the United States to the south of the boundary are much higher than those just mentioned, reaching 7000 feet or more.

The Andes show marked contrasts on east and west. The Pacific slope is relatively dry, while the Atlantic moisture spreads far over the Amazon plains and en-

Fig. 90. — Pass between the Moose and Smoky rivers.

riches the head-waters of this master river on the east slopes of the mountains.

In the Old World the Pyrenees are an effective wall between France and Spain. But two railways join the countries; one of these follows the shore of the Bay of Biscay, and the other is close to the Mediterranean. Carriage roads cross the range at but two points. The Alps are higher and more rugged than the Pyrenees, and throughout historic time have stood as a barrier between the Mediterranean and central Europe. On the south is the subtropical and sunny Italy. On the north are the cool temperatures and sombre skies of Germany. But the passes, as compared with the Pyrenees, are low

and numerous, and have been trodden by travellers, merchants, and invading armies since Roman days. Trails, beautiful carriage roads, and railways have in turn assumed the chief importance.

In Asia, the mild, fertile, and crowded districts of India are shut off from the high, cold, wild, and sparsely peopled lands of Tibet by the Himalaya Mountains, while the several mountain ranges of central Asia lie between the Russians on the north, and the British, intrenched in India, on the south.

CHAPTER IX

VOLCANOES AND EARTHQUAKES

We shall begin our study by looking at several well-known volcanic regions, the one about the Bay of Naples, the Hawaiian Islands, and Mount Shasta. We shall then compare these volcanoes, and see what great principles we can find to help us understand this part of the earth's machinery, which is so strange to most dwellers in Canada. The first examples are chosen outside North America, because here the volcanoes have nearly ceased to be active. But it is well to mention at the outset that nowhere have the fires of the earth had more effect on the surface, in past ages, than in some parts of our own land.

Figurative terms. — The word "fire" in the last sentence, and in other passages of this chapter, is not used in its ordinary sense, but somewhat figuratively. When fire burns, two substances combine — for example, coal and oxygen — and heat and light are caused. The substances are said to be consumed. In the volcano nothing is consumed; the lava as it comes from below is already in a hot and glowing condition. Before the real facts were known, people believed the heat was caused by burning, and the words expressing this belief are still sometimes used in speaking of volcanoes. Among these misleading terms are flame, ash, cinders, and igneous (fiery) rocks.

Vesuvius. — If one were to visit the west coast of Italy and ascend Mount Vesuvius, he would find an observatory part way up the slope, where for many years Italian scientists have watched the behaviour of the volcano. This small mountain, about 4000 feet high, rising from

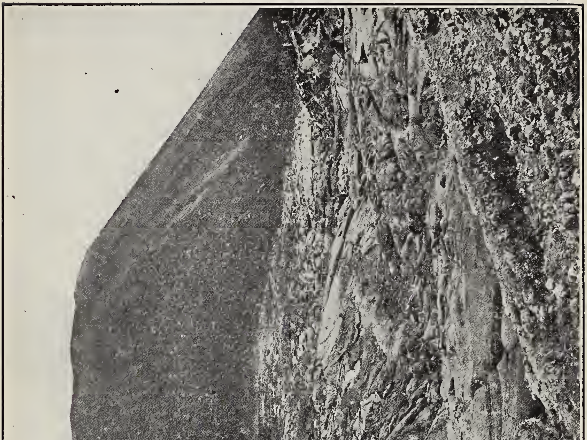


Fig. 91.—Mount Vesuvius; a near view of the top in 1880

the shore of the Bay of Naples, is a typical volcano; the better because it has been studied so long, and its principal changes for nearly 2000 years have been recorded.

Near the shore west of the Bay of Naples is Monte Nuovo, or new mountain, a hill 440 feet high, cast up by volcanic action during a few days in September, 1538. All about it are volcanic hills of earlier origin, and two

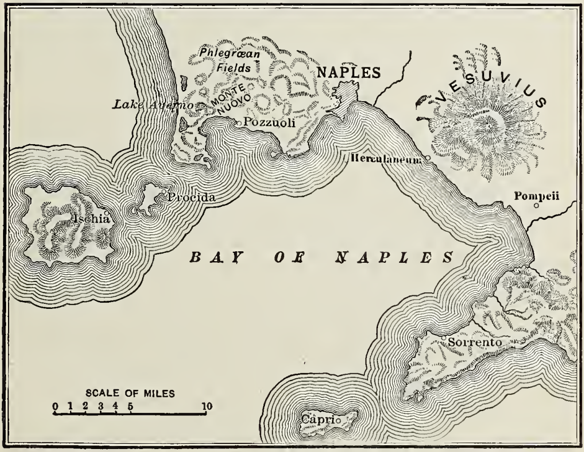


Fig. 92. — Map of Mount Vesuvius and vicinity.

islands bordering the bay are also volcanic. Thus we learn that Vesuvius is not alone, but is surrounded by a district under which the volcanic heat has been more or less active. The whole region is subject to earthquakes, due, it is believed, to the pent-up forces below; and when the volcano gives vent to the confined lava the earthquakes subside.

Sunk into the top of the mountain itself is a bowl-

shaped depression, the crater. In it is molten rock, and from it there come forth steam and other hot vapours. When the wind is blowing in the right direction, the edge of the crater may be reached and a look had into its fiery depths. When a powerful eruption begins, immense clouds of steam rise and spread above the top of the mountain, taking a form that has often been likened to a pine-tree. It is not smoke, but vapour, that pours out; and the glow often seen, especially at night, is not flame, but the reflection from the vapour clouds of the light that flashes up from the melted rocks, either in the crater or overflowing in streams that roll down the sides of the mountain.

These streams sometimes flow so fast as to overtake a man running swiftly. At other times they creep. The differences depend on the slope and on the consistency of the lava. Some lavas are thick and viscous, like molasses; others are thin and watery. If the stream is shallow, it cools quickly and comes to rest. After lava has flowed for some distance the surface cools and is brittle, while the lower parts are soft and hot. As these lower parts push on they break up the surface into a rough, clinkery mass, which appears like a creeping heap of slaggy boulders. After the lapse of a human lifetime a lava stream may still send steam forth from its crevices, while the surface has long been cold, hard rock. Lavas are often frothy, with hot vapour in the form of bubbles, and after cooling to rock are full of rounded pores or cells. Certain lava-rocks are so porous and filmy that they will float on the sea. The pumice-stone used in the arts is a volcanic rock.

As the lava streams of Vesuvius have poured down its sides they have added successive coats to its slopes, thus increasing the size of the mountain. But not all the growth of the cone is thus explained. Some eruptions

take place by means of powerful explosions, whose seat is somewhere below the outside opening. In this case the interior rock comes out, not as lava, but in the form of fine dust, or coarser pieces of rock, which fill the air, and fall or slowly sink to rest on the sides of the mountain or on neighbouring plains and seas. Built up in these two ways, the mountain mass is a mixture of lava torrents and " ash " beds.

The student will observe that the height of Vesuvius was given as *about* 4000 feet. It is not always the same, and has varied several hundred feet during the Christian era. In early Roman times the volcano had always been quiet, though previous to 79 A.D. the neighbourhood was shaken by earthquakes. In this year there was a great eruption. There was no lava, but immense quantities of ash were thrown out and rained on the neighbouring land and sea. Two cities, Herculaneum at the west foot, and Pompeii at the south base of the mountain, were buried and lost for many centuries. Had they been deluged with lava, they could not now be uncovered and seen in such perfection — walls, pavements worn by wheels of carriages, rooms, wall-paintings, utensils, and all the signs of the luxury of the inhabitants. As the centuries have passed, other outbursts have sent forth streams of lava as well as clouds of dust and ash. Sometimes the top of the cone has been cut off several hundred feet by a great explosion, only to be slowly built up again by the contributions of more quiet eruptions.

Another eruption of Vesuvius took place in 1906. Four towns and a number of villages were destroyed and more than 2000 people killed. The stream of lava reached as far as Pompeii, and ashes fell in such quantities in Naples as to break down the roofs of large buildings with their weight. The top of the mountain was blown off, the height of the crater being reduced by 700 feet.

Other Mediterranean volcanoes. — With what we have learned about Vesuvius, it will now be useful to associate some facts about other volcanoes in the middle Mediterranean region. South of Naples, near the Straits of Messina, are the Lipari Islands. They are composed of volcanic rocks. Of several volcanoes in this group Stromboli is best known, because it is always active. Like Vesuvius, it is sometimes explosive and sometimes quiet, giving forth both molten and broken material. Its per-

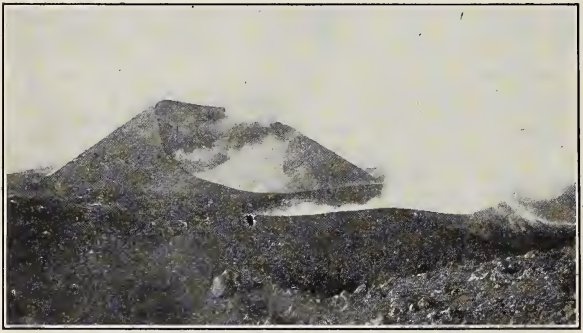


Fig. 93. — Mount Silvestri and a lower cinder cone, on the side of Mount Etna, as they appeared August 19, 1892.

petual column of steam, illuminated at night with unfailing regularity by the fires of the crater, has caused it to be known as the "Lighthouse of the Mediterranean."

Still southwards, close by the eastern shore of Sicily, rises another volcano, in comparison to which Vesuvius is but a mound. Etna is more than 10,000 feet in height, and has a circumference of 40 miles. Like Vesuvius, this vast cone is built chiefly of lavas and loose materials coming to rest about a central pipe or throat leading up from the depths, but there have also been many small eruptions on the flanks. From time to time cracks open on the

sides of the great cone, allowing the escape of lava and cinders and causing small cones to be built. Like other great mountains, it has a rugged surface, and rises through several zones of climate, being almost tropical at its base, temperate and forested on its middle slopes, and arctic and snowy towards its summit.

In 1831 the sea south of Sicily gave a notable illustration of the volcanic habit of that region. At a point where the water was 600 feet deep, volcanic materials were cast up until they stood 200 feet above the water. This new island, however, was soon cut away by the sea waves, leaving a shoal where the transient land had been.

Hawaiian volcanoes. — The Hawaiian Islands form a north-west by south-east chain, about 400 miles long. All

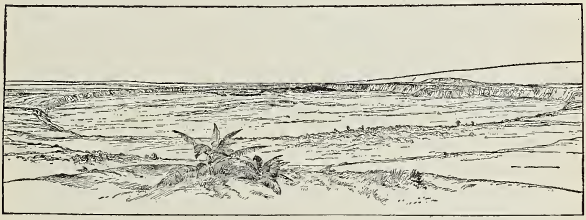


Fig. 94. — Kilauea, the great crater of the island of Hawaii.

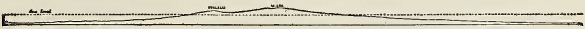


Fig. 95. — Profile of the island of Hawaii, through Mauna Loa (13,675 feet), showing gentle slopes and the extent of the volcanic mass below the sea. Scale, 1 inch = 36 miles.

are volcanic piles built up from the floor of the deep seas. The only active volcanoes, however, are on Hawaii, the south-eastern member of the series. This is a large island, about 80 miles across and having the form of a rude triangle. The two highest volcanoes are Mauna Loa and Mauna Kea, rising nearly 14,000 feet above the sea.

The total height above the sea-bottom is about 30,000 feet, or in the neighbourhood of 6 miles. If the sea could be drained away, this whole island would be a broad-topped mountain, as high as the loftiest summits of the Himalayas. Successive outpourings of lava have reared the islands from the floor of the sea. The work even of Etna is insignificant as compared with this.

The slopes of the Hawaiian cones are very gentle. This is due to the fact that the rocky matter sent forth

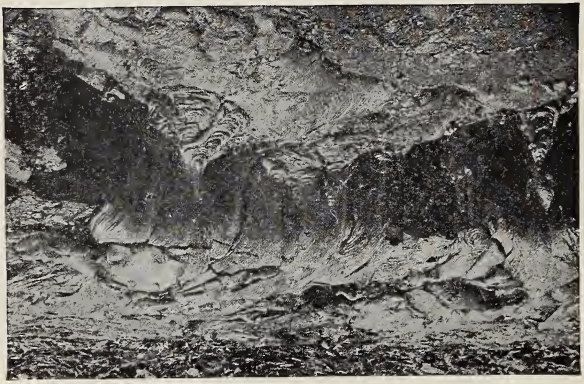


FIG. 96. — A congealed lava cascade; Hawaii.

is all in the form of lava, and the lava is in a very liquid condition. Hence when it flows out, it spreads widely. Thicker lavas and falling fragments build steeper cones. There is a great difference between the craters of Vesuvius and Hawaii. The one is a narrow, steep-sided bowl, the others are broad, sunken basins several miles across. The walls of the Hawaiian craters are cliffs several hundred feet high, but at some points descent may be made. During the time of quiet between eruptions, the traveller finds a floor of cooled lava covering over most of the crater

basin. But at some points there are small ponds or lakes of molten lava, which bubbles and sputters with the escape of hot vapour.

The eruptions are vaster but more quiet than those of many small volcanoes. For a number of years the lava may rise, and spread in the crater, so that the basin can no longer be entered. But it has not been known to flow over the rim. Before this is reached it pushes through deep-seated cracks and issues on the sides of the mountain, often several miles away from the crater, and flows down the slope as a great hot river. Being very liquid at the start, it flows long distances, sometimes as far as 50 miles. Sometimes it has reached the sea-shore, and there, like a waterfall, has poured over the sea-cliffs upon the beach below.

Much of the surface of the islands is mantled with soil and forest. But where the outflows have been recent, as over a large part of Hawaii, the lava surfaces are rugged and utterly barren. These rugged surfaces weather rapidly in such a moist climate, and in a few years are covered with vegetation. In the forested regions streams are abundant, and some of them have worn out deep gorges which add variety to the surface. Thus volcanic action, weathering, and stream erosion combine to give the land its form and expression, and the climate, moist and tropical, clothes much of the surface with ferns, breadfruit-trees, screw-pines, and cocoanut palms.

Krakatoa. — Like the Hawaiian group, many islands of the Pacific Ocean are volcanic. They are the "high" islands, in distinction from those that are low, or of coral origin. Krakatoa is an island volcano, lying in the strait that separates Sumatra and Java. It was not known as a great volcano until August, 1883, when for two days a succession of explosions blew away about half of the island mountain, brought the neighbouring seas and lands

to total darkness, impeded the sailing of ships by the pumice that fell on the sea, and gave forth reports which were heard in Bangkok, in the Philippine Islands, in Australia, and more than 2000 miles to westward in the Indian Ocean. Dust fell on ships 1600 miles away, and is believed to have been carried in the upper air around the world.

Mount Shasta. — This volcano is no longer active, but is none the less useful for comparison with those already

FIG. 97. — Mount Shasta. This picture shows only the older summit, the younger being hidden behind it.

studied. It is in northern California and rises to an altitude of 11,000 feet above the neighbouring lowlands. Its slopes are steep above, and become gradually gentler below, until they merge with the plain. The upper part of the mountain is double, its two summits marking two principal points of eruption. The higher is also the older; it had been completed and had begun to waste away before the building of the other.

If one were to dig deep into the mountain mass he would find various beds, some of ash, bound into firm rock, and some of cool lava, thus showing that, like Vesuvius, the volcano was sometimes explosive and sometimes sent streams of molten rock welling forth from its crater. On the lower slopes of the mountain are smaller cones, and some of these are much younger than either of the great peaks. From one of them a lava stream flowed to the Sacramento River and followed its valley for 50 miles. The river has since opened a canyon across it, and elsewhere sunk a deep channel at its side so as to leave the lava plain as a high terrace.

For a long period, as we reckon time, the lava below the mountain has cooled, or at least has been unable to send forth signs of its presence. We call the volcano *extinct.* Instead of red-hot lava, glaciers cling to its upper slopes. There are five of them, two to five miles in length, each scooping a glacial alcove and trough out of the sides of the peak, and strewing the space below with moraine, or sending rock-flour and pebbles down the torrent courses of the mountain. The torrents have dug deep gorges. So the forces of waste are striving to tear down what the volcanic forces have built up.

Other volcanoes of the western United States. — If we go northwards from Mount Shasta along the Cascade Range of Oregon and Washington, we find magnificent volcanic peaks, of which the highest is Mount Rainier, rising to 14,500 feet above the sea. As measured by the amount of wear, it is older than Shasta. Its glaciers and torrents have deepened and enlarged their valleys until the intervening ridges are narrow and crusted. It may be said also to have renewed its youth, for after the work of destruction had made great progress, eruptions broke forth once more, and constructed a well-formed cone and crater at the top. Mount Hood, Mount Jefferson, Mount

St. Helens, and Mount Baker are among the other volcanoes of the region. All of these lofty peaks are white above and forested below. "Could an observer obtain a bird's-eye view of the Cascade Mountains, they would

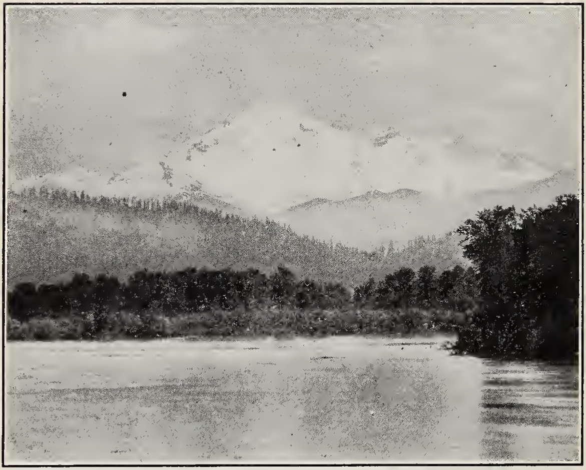


Fig. 98.—Mount Baker. A beautiful view of this mountain is obtained from Victoria, B.C.

appear as a belt of emerald studded at irregular intervals with immense brilliants" (Russell).

Volcanoes in Canada. — Canada contains no active and very few well-preserved extinct volcanoes. A recent explorer has described a volcanic cone 1000 feet high with a crater 450 feet deep near the Yukon River. From a break in the wall of the crater the last lava flow streamed towards the east. There is also a thin sheet of white volcanic ash to be seen just beneath the soil for many miles along the upper Yukon River, showing comparatively recent volcanic activity in that part of Canada.

Regions of active volcanoes. — Volcanoes are confined to no part of the world, but form one of the common features of the earth's surface. The Atlantic Ocean contains many volcanic islands. Iceland is one of the most northerly and important. Its lava streams are of great size, while the ash from one of its volcanoes has fallen on ships in the northern seas, has descended on Scandinavia, and has even injured crops in the north of Scotland. Farther south, the Azores, Canary, Cape Verde, St. Helena, and other islands are volcanic.

In the West Indies is a line or narrow belt of volcanoes 500 miles long. They make the higher islands of the Lesser Antilles, including, among others, St. Kitts, Guadeloupe, Martinique, and St. Vincent. Because they are arranged in a line, it is thought that they are related to one another in origin, and make up a system. Their eruptions, though not frequent, have been energetic and destructive. Here, as about Vesuvius, the long periods of rest have given a false sense of security, and tempted to extensive settlement on the rich volcanic soils, to be followed by fearful disaster when activity was resumed. There were outbreaks on St. Vincent in 1718 and 1812, on Guadeloupe in 1797, and on Martinique in 1851. The outbreak of 1812 was an explosion almost rivalling that of Krakatoa. A crater called Saufrière was either created or greatly enlarged, the fertile lands of the island were overwhelmed by ashes, and the town of Caracas, with 10,000 inhabitants, suffered the fate of Pompeii.

In May, 1902, the attention and sympathy of the world were again drawn to these unhappy islands. The Soufrière, after a rest of ninety years, and the Pelée volcano on Martinique, which had slumbered for fifty-one years, again wakened to activity. Explosions scattered stones and ashes widely over the lands. Streams of hot mud flowed from the craters to the sea. A new crater opened

on the slope of Mount Pelée. A sudden blast of hot gas and cinders from this destroyed the city of St. Pierre. More than 30,000 inhabitants of the islands lost their lives, and great areas were laid waste.

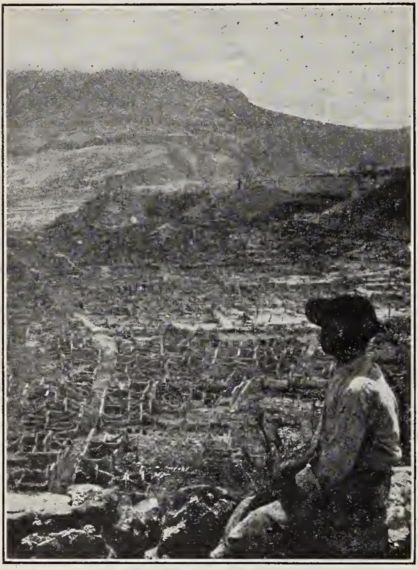


Fig. 99. — Mount Pelée and the city of St. Pierre after the eruption. Copyright by Underwood & Underwood, New York.

We have already told of a few great cones of the Pacific coast region. Following the mountain belt through Mexico and Central America and far along the Andes, great volcanoes are abundant and active. Northwards, a few volcanoes occur on the islands of southern Alaska, and a great volcanic belt, beginning on the south coast of western Alaska, may be followed almost around the Pacific Ocean. The Aleutian Islands, Kamschatka, the Kurile Islands, Japan, the Philippine Islands, and those of more southern seas, with the mountains of western America, almost girt this vast ocean with fire, while many a chimney, as we have seen, rises from its waters, and many submarine volcanoes

have not been able to pile their outpourings to the surface of the sea. Krakatoa belongs to a field of great volcanic activity, including Java, Sumatra, and almost all parts of the East Indies.

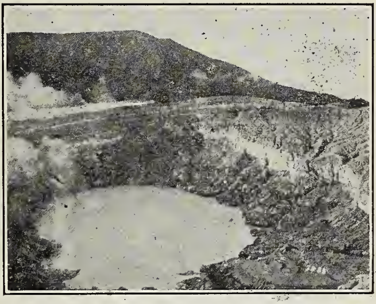


FIG. 100.—A volcanic crater, holding a lake, Costa Rica.

History of a volcanic cone.—This is a story of growth and decay. Vesuvius, Etna, and the Hawaiian cones are still growing. The time was when their piles of volcanic matter were small like Monte Nuovo. Through progressive stages they have grown to be what they are. In time they will cease to send forth ash and lava, and destruction will begin. We see the first stages of it in Mount Shasta. Here the form is still well preserved and the mountain has lost little from its top and sides; but there has been some wasting.

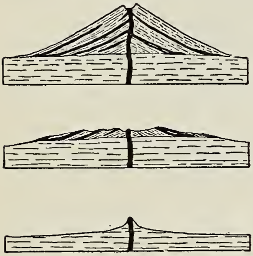


FIG. 101.—Ideal sections of a wasting volcanic cone at three stages of its history.

In older volcanoes, destruction has gone much farther, and the loose materials of the cone may all have been washed away. But the lava that occupied the old throat, far below the crater, is harder than the surrounding rock, and in the great wasting, has survived and stands above the surface. It has been well likened to the cork in a

bottle, and geologists call it a *volcanic neck* or *plug.* Many of them stand out on the surface of the plateau in parts of New Mexico. The central part of Montreal Mountain is believed to be a very ancient volcanic neck.

Sheets of lava. — While no lavas are so fluid as water, they show great differences in this respect. Some are very stiff and can scarcely flow at all; others are thin and flow easily. When a lava stream starts from a crater, it also begins to cool and it stops flowing when it gets so cool as to be stiff. If the amount which comes out is small, it stops quickly. The piling up of such short streams makes volcanic mountains. But sometimes a very large quantity of very thin lava escapes all at once, and then it runs farther and spreads more widely. If it runs into a valley or over a plain it makes a lava lake. When it hardens it makes a broad, flat sheet of lava-rock. In the basin of the Columbia River there have been many such eruptions, with the result that broad plains are composed wholly of volcanic rocks, piled up in sheets. The Snake River, crossing such a plain, has made a long, deep canyon in the walls of which the sheets or beds of lava-rock

Fig. 102. — Obsidian cliff, Yellowstone Park, Wyoming, U.S.A.; showing the splitting of lava into columns.

are arranged like the beds of sandstone and limestone in the canyons of the Colorado. Before the eruptions began, the region had for long periods been a district of mountains and valleys. Hence the outpourings flooded the valleys and low grounds, while the higher mountains still rise as islands from the plateau, or send out ridges or spurs from its border. Thus the boundary of the lava sheets runs in and out, like the shore-line of a lake in a rough country.

There have been volcanic eruptions in all the past ages of the earth. Some of these spread under the ocean and were covered by sediments, and so there are lava-rocks buried among the stratified rocks. Lavas have also intruded themselves in broad sheets between strata, and there hardened to rock. Afterwards, when great series of strata have been lifted into the air and gradually wasted away, the sheets of lava-rock have been exposed to view; and, being very durable, they often stand forth in the landscape as hills and ridges. The hills of the Port Arthur region are due to such lava sheets. The cliffs at the edges of the sheets have a peculiar character because of a tendency of lava-rock to break up into columns. It shrinks and cracks in cooling, and the cracks run far into it, dividing it into long blocks with five or six sides.

FIG. 103. — Thunder Cape, near Port Arthur, Ont.

Extensive sheets of lava are found in Colorado, Utah, Arizona, New Mexico, and other western States, and in the Yukon Territory between the Pelly and Yukon rivers. In western Scotland also are important lava sheets. Here belong the columnar rocks of Mull, Staffa, and other islands, which consist largely of remnant lava-beds. Into the southern cliffs of Staffa the sea has worn Fingal's Cave by removing the vertical columns of lava. The Giant's Causeway, on the shore of Ireland, consists of similar volcanic rock. One of the largest outpourings in the world forms the plateau known as the Dekkan in India. The lavas there are sometimes 6000 feet thick.

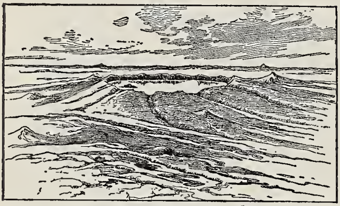


Fig. 104. — Bird's-eye view of Crater Lake, Oregon.

Volcanic lakes. — These may be formed in at least two ways: A flood of lava sometimes blockades a valley; behind such a dam a lake will form and remain until the basin is full of sediment, or the outlet stream saws through the barrier. And when a volcano becomes extinct, its crater may serve as a water-basin. Crater Lake, in southern Oregon, lies in the heart of an old volcano, the higher and central parts of which have disappeared. Instead of an explosion, as in the case of Krakatoa, there was a withdrawal of the lava beneath, so

Fig. 105. — "Mount Mazama," an ideal restoration of the Crater Lake volcano. See Fig. 104.

that all the upper part of the cone, with its gorges and glaciers, fell in and disappeared, leaving a nearly circular pit 4000 feet deep and 6 miles wide. The water of the lake is 2000 feet deep. Above it rises an island, which is a small volcanic cone, made after the disappearance of the greater cone.

Volcanic soils. — Lavas and ash are often so porous that they are easily entered by air and water, and weather rapidly into soils. Thus, after a few generations, the lava fields about Vesuvius, and other volcanoes in genial climates, become densely populated, and all danger from eruptions seems forgotten. Parts of the Dekkan are important in wheat and cotton growing, and the black and fertile soil is due to the decay of the lavas. In the same way lavas furnish the soils for extensive wheat-fields in Oregon and Washington. This is perhaps the most important way in which volcanoes affect mankind, unless we except the catastrophes which have wrought destruction of life. The volcano does not compare with weathering or with streams; and it probably has not influenced the more progressive races so extensively as has the glacial invasion. Certainly glaciers, much more than volcanoes, have moulded the conditions of life in North America.

Causes of volcanic explosions. — The general causes of volcanoes are not well known, but the reason that lavas sometimes explode is better understood. There is water in all lavas, the quantity being large in some and small in others. Deep down in the earth's crust the pressure is so great that the water, though intensely hot, cannot change to vapour; but as the lavas rise they experience less and less pressure, until at last the water within them suddenly becomes steam and is instantaneously expanded. If there is little water, the lava quietly bubbles; if there is much, it is torn to fragments, and the fragments are hurled into the

air. The principle of the explosive volcano is the same as that of the geyser.

Summary of principles. — The descriptions of particular volcanoes and districts have illustrated various general facts, and some of these have been pointed out. We now bring together the more important:

(1) Many volcanoes build around their vents a cone; it may be of mountainous height, and the term mountain, in a general sense, is commonly used. It is not at all due to uplift of the earth's crust, but to the bringing up of materials from below which are heaped up about an opening. In this respect, as well as in form, the volcano finds its miniature representative in the ant-hill.

(2) Some cones are large both in height and base, like the Hawaiian, while others are small, like Vesuvius, Stromboli, or the diminutive Monte Nuovo. They also differ in form; some are very flat and others as steep as a talus of coarse waste, the difference being due to the character of the materials forming the pile.

(3) The materials sent forth are various. First, we have the lavas, and these differ much. Some are dark and very heavy, as basalt, and others are pale in colour and lighter in weight. Second, we find the ash, with larger angular pieces of rock, as in some eruptions of Vesuvius and Shasta, or the great eruption of Krakatoa. Of importance also are the vapours, particularly the steam, which often condenses and causes heavy rains, or mixing with the ash gives rise to eruptions of mud, which flow from the volcano and harden into rock. Any volcanic ash which thus becomes bound into firm rock is called *volcanic tuff*.

(4) Volcanoes differ much in the manner of eruption. Stromboli is constant; Vesuvius and the Hawaiian volcanoes are intermittent or spasmodic. Some are quiet; others are violent and explosive. Some vents emit many

small eruptions and build up mountains; others discharge great volumes of their lava and construct plains.

(5) Craters are formed in various ways. Fragments thrown out by explosive eruptions fall to the ground all about the opening, and thus build up a circular rim. Sometimes a great explosion blows off the upper part of a conical mountain, leaving a hollow in its place. And sometimes the interior of the mountain is melted out, letting the top fall in.

(6) A volcano, like a mountain range, is caused by forces belonging to the mysterious interior of the earth. As soon as made it is attacked by the destructive forces of air and water, which gradually wear it away. Growth and decay make up the history of its life.

Earthquakes

In volcanic regions. — The earthquake and the volcano often go together. Thus, earthquakes are common about Naples and Mount Vesuvius. Before the great eruption of 79 A.D., shakings of the earth had occurred for several years. When the energy that had been sealed below the surface broke forth, the shaking ceased.

Earthquakes occur also quite independently of volcanoes, and all of the most destructive earthquakes have been of the non-volcanic class. In a great earthquake the ground shakes so violently that trees are broken or overturned; men and animals are thrown down; many fissures are opened in the ground; new springs are made and some old springs cease to flow; in the mountains are rock-falls and landslips; in the cities houses are wrecked and many of the inhabitants perish. In one place the ground may be permanently lifted, and in another depressed so as to cause a lake. On the shore the inrushing of great waves may destroy many lives and houses, and ships have thus been carried landwards and left high and

dry. Such are the features close to the earthquake centre. Farther away there is less violence, but the tremor is felt for hundreds of miles in all directions, gradually lessening in force as the distance is greater. It travels outwards from the central tract just as waves circle outwards when a stone is dropped in the still water of a pond. The earthquake wave does not stop at the limit of the area in which it is felt, but continues as an unfelt swaying completely

Fig. 106. — The earthquake at Messina, 1908. Courtesy of "The Canadian Courier."

around the earth. In remoter regions, it is detected by means of instruments of wonderful delicacy called *seismographs*, and from the records of these instruments men have learned that the greater number of strong earthquakes have their centres under the ocean.

Some countries, like Japan and Calabria, are notable for the frequency with which they are shaken; others have suffered from single shocks of great power. Among the most destructive convulsions were the Lisbon earthquake of 1755, the Japanese earthquake of 1891, the Indian

earthquake of 1897, and the Calabrian earthquake of 1908. During this latter earthquake, the large city of Messina, in Sicily, with many smaller towns on the mainland, was destroyed, with the loss of more than one hundred thousand lives, arousing the horror and pity of the world.

FIG. 107. — The San Francisco earthquake. Copyright by Underwood & Underwood, New York.

The San Francisco earthquake. — No serious earthquake has visited Canada in recent times, though several destructive shocks have occurred in parts of the United States, such as the Charleston earthquake of 1886, and the Alaska earthquake of 1899. The latest and most carefully studied took place in California early in the morning of April 18, 1906.

The earthquake and the fires which broke out soon after destroyed most of the city of San Francisco, fortunately with much less loss of life than in some other recent earthquakes. The destructive shock lasted one minute and five seconds, during which most of the large buildings in

the city were thrown down or greatly shattered. The breaking of the water-pipes prevented the putting out of the fires which immediately started. It is probable that the conflagration was more destructive than the earthquake itself.

It has been found that this earthquake was caused by the shifting of blocks of the earth's crust along a line of dislocation or *faulting,* which has been traced for more than three hundred miles. The worst destruction took place within ten or twenty miles on each side of this line. After the first great shock, there were a number of minor ones which did little damage beyond throwing down already tottering walls. It is believed that former earthquakes in the region have come from adjustments along the same fault plane. The greatest damage was done on low, made ground, and the least on the solid rock in the higher parts of the city.

What is an earthquake ? — It is not so easy to answer as to ask this question. As it is quite clear that the rocks receive an impulse which spreads out in every direction, the real question is, What is the force that gives the impulse? When an earthquake accompanies a volcanic explosion, the same force evidently causes both — the expansive force of steam. In other cases it is thought that the forces which lift mountains and those which push lavas through the crust are able to bend or strain the rocks, and the straining gradually increases for a long time, until at last there is a sudden breaking, which gives the earthquake impulse. The fracture may be far below the surface of the ground, so that it can be known only by its effects, or it may reach the surface, as in the case of the California earthquake, making a visible crack.

CHAPTER X

THE ATMOSPHERE

We now pass from the forms of the land to the study of the *atmosphere*, which covers land and sea and has much to do with both. The word means "vapour ball," and is thus a good name for the envelope of the globe. It lies outside the watery sheet which so nearly covers the planet, and the water in turn mantles the rocky crust. Thus the inner parts of the earth may be thought of as having three covers — of rock, water, and air. The atmosphere is a part of our globe, and not merely an outside blanket.

Composition of air. — Air is the name of that mixture of gases which makes up the atmosphere. Before we give an account of these gases, we may notice certain facts about the air. As it has neither odour, taste, form, nor colour, we cannot smell, taste, or see it. We feel it when it is in motion or when we move through it, and we notice keenly whether it holds much or little heat. Our hearing depends entirely upon wave motions which spread through it. It is elastic, and expands and contracts by changes of temperature, and when pressure is withdrawn or applied. It can be turned into liquid, a property whose importance may prove to be very great. It is essential to combustion as well as to the slow processes of decay, and is required, in larger or smaller amounts, by all animals and plants.

Air is made up chiefly of the two gases, oxygen and nitrogen, in the proportion of one part of the former to four of the latter. The two are not chemically joined, as the hydrogen and oxygen of water, but are mechanically mixed. To stir ashes with soil would roughly illustrate

the mingling of the invisible molecules of oxygen and nitrogen. The oxygen is the active element in burning, in decay, and in living bodies. It unites with certain substances and heat is given off. If this process goes on rapidly, and much heat appears, we call it burning. In our bodies this action is constant but slower, and with less heat. In decay the process is very slow, and the heating is correspondingly little.

The nitrogen, while large in amount, is the inactive element in the air. It does not unite with other substances, but without it the activity of the oxygen would be destructive. Animals cannot breathe pure oxygen. Nitrogen serves for the air the same purpose as the dilution of a strong liquid by water.

Carbon dioxide, often called carbonic acid gas, is a combination of carbon and oxygen. It is present in the air in very small amount — about 0.03 of one per cent — but is of very great importance. Plants take in this gas through the leaves, break it up, use the carbon, and release the oxygen. Animals, on the other hand, breathe in oxygen, and give off carbon dioxide. It is the presence of this, and other harmful vapours from the body, that makes the ventilation of sleeping and living rooms important. This gas is given off in all ordinary burning, hence the use of gas and oil lamps without sufficient supplies of fresh air is harmful. We thus see that a gas which is a deadly poison to animals in any but minute quantities is necessary to the life of plants, and thus indirectly to all animal life. Certain other gases are in the air in very small amounts, but we need not concern ourselves with them.

The vapour of water is always present, but the quantity is very variable. It is gathered by evaporation, mainly from the ocean, and is floated everywhere by the winds; as rain, it waters the fields and forms the rivers. All the life of the land depends upon it, and the forms of the land

also, as moulded by solution, river, and glacier. In later sections we shall study humidity, dew, frost, clouds, and rainfall. All these topics relate to moisture in the air.

Fine dust is everywhere present, especially in the lower levels of the atmosphere. It is not a part of the air, but floats within it. We can sometimes see its particles when a beam of sunlight enters a poorly lighted room. The haze following great forest fires, and the pall often hanging over manufacturing cities, are due to dust. All man's operations cast more or less dust into the air. The winds blow fine plant and mineral fragments up from the forests, roads, and fields, and explosive volcanic eruptions scatter dust widely. When heavy rains follow a period of drought, the dust is washed from the air, and we say that the air is cleared. When rain-water is gathered in tanks and cisterns, some of the dust appears as sediment. Not least important are the minute living things which are always found in the air, and may be blown to long distances. Such are seeds and the pollen of flowers, and especially the microscopic germs of many diseases.

Weight and height of the atmosphere. — Air, though a mixture of gases, is a material substance, as is well shown by forcing it into liquid form. It has weight, therefore, though much less than a liquid or solid. In the space of a cubic foot there is more than an ounce of air, and an ordinary school-room contains several hundred pounds. Because of its weight, air pushes downwards, pressing on the ground and the ocean. The upper part of the atmosphere also presses on the lower part. Though the atmosphere is really not separated into parts, we may think of it as composed of horizontal layers, resting one on another, and thus compare it to a pile of boards. Just as each board bears the weight of all the boards above it, so each layer of air is pressed upon by the weight of all the air above it. The boards are unyielding, but the elastic air is crowded

together by the pressure — like a dry sponge or a coiled spring. The greater the pressure, the more the air is packed together. So low layers of air, sustaining great weight, are comparatively dense, and high layers, sustaining less weight, are comparatively thin or rare. There is a gradual thinning from the level of the sea upwards; about the top of Mount St. Elias the air is only half as dense as about its base. Therefore, on a high mountain the lungs get less air at each breath, and one must breathe quickly to keep them supplied. A very little exertion makes one pant violently.

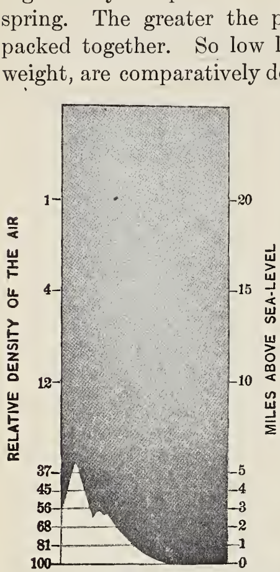


Fig. 109. — Diagram of the atmosphere. Varying depth of shade indicates varying density. The highest peak corresponds to the Himalaya, the lower peaks to the Sierra Nevada and Rocky Mountains.

In the first few miles of ascent the air thins more rapidly than at greater heights, and the change finally becomes very gradual. Reasons have been found for feeling sure that very thin air exists at the height of a hundred miles. How much farther out into space the last scanty remnant of our atmosphere reaches may never be known. By far the greater part of it, as measured by weight, lies below the level of the highest mountain tops.

Humidity. — This is a scientific term which is also much used in common speech in referring to the moisture of the atmosphere. If there is much moisture we say that the *humidity* is great. In warm weather the air is heavy and

lifeless, and we call the day or the night sultry. In addition to the depressing effect, we perspire freely. Moisture is always escaping from the pores of the skin, but in dry weather it evaporates. Warm and humid air about us is like a filled sponge, refusing to absorb more, hence the drops gather on the body. If the air is cold and humid, it brings chill and a cutting sensation upon exposure. In dry, hot days the air is like an empty sponge — it absorbs readily; plants lose their moisture through the leaves and wilt; washed clothes dry rapidly, and we say the humidity is low.

The warmer the air, the more water vapour it can hold. The sun's heat, falling on the sea, on rivers, and on moist earth, causes evaporation. If the air has thus taken in all the vapour it can hold at a particular temperature, and the temperature be lowered, some of the invisible particles will fly together — that is, *condensation* will take place — and there will be fog, clouds, dew, rain, or snow. Thus the atmosphere is always receiving water in some places and yielding it up in others.

If air at a temperature of 75° (or any other degree) has all the vapour it can hold, it is said to be *saturated.* Its vapour contents exactly equal its capacity for vapour, and hence the relative humidity is said to be 100 per cent. If the same air were filled to only half its capacity, the relative humidity would be 50 per cent. If now we gradually lower the temperature, but keep the amount of water the same, we come at last to the point of saturation, and the relative humidity becomes 100 per cent, instead of 50 per cent. Relative humidity does not tell us how much water there is in the air, but it gives the ratio of the moisture present to that which the air at that temperature is able to hold.

Dew and frost. — As night comes on the sun's heat is removed, the air grows cool, especially near the ground;

its ability to hold moisture decreases, and it may become saturated — that is, the relative humidity may become 100 per cent. If now the temperature continues to go down, the vapour will condense and be found on grass and leaves, and even sometimes on roofs and stones. This is *dew.* The temperature at which it begins to form is known as the *dew-point.*

Not all of the drops which in the morning sparkle on blades of grass and leaves of shrubs and trees have come from the air. Many of them have travelled up through roots and stems and have been *transpired* by the leaves. This goes on by day also, but the water is at once evaporated, because then the air near the ground is warm. Thus plants as well as animals condense the vapour on their outside surfaces when the air is overcharged with water.

When the air is comparatively dry (relative humidity low), and the drop in temperature is slight, there will be no dew, the point of saturation not being reached. Dew is not apt to be formed on cloudy nights, because the clouds prevent the rapid cooling of the ground. It will be understood that the dew does not really "fall," but gathers by direct contact with moist air.

If the surplus moisture from the air or from the ground condenses at temperatures below the freezing-point, we have *white frost,* or *hoar frost,* instead of dew. It is most noticeable in autumn and spring upon roofs, fences, and fields. Clouds often prevent frost by holding in the heat which has accumulated during the day, and we sometimes imitate nature by covering plants on clear nights to protect them from frost.

Clouds and fog. — Fog is a cloud in the lower air. If the dew-point is reached at the earth's surface, moisture gathers there. If a few feet or a few hundred feet of the lower air cool to the dew-point, *fog* is formed. The par-

FIG. 110. — Cirrus clouds.

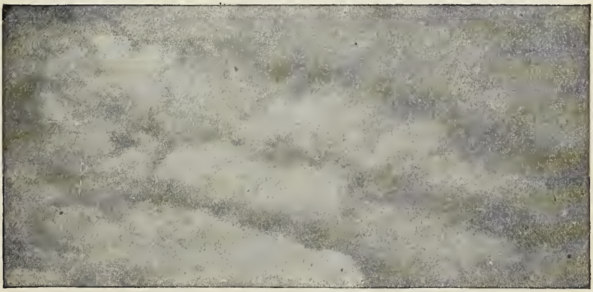


FIG. 111. — High cumulus clouds.

FIG. 112. — Low cumulus clouds.

ticles of invisible vapour unite and become visible, but are still so small that the air supports them. Thus it is that a thin layer of mist may spread over a swamp or valley bottom, so that from a hilltop we may look out over a lake of fog. In the rays of the sun the air grows warmer, and when the relative humidity falls below 100 per cent the fog evaporates.

Clouds are not different from fogs except that they are higher in the air. If we ascend a mountain which is wrapped in cloud, we find ourselves enveloped in fog. Clouds are caused by condensation resulting from the cooling of the air. The cooling may be brought about in various ways, but is usually occasioned by an upward movement of air. So also clouds are sometimes dissolved when air is warmed by downward movement. We shall see how the rising and sinking of bodies of air make them cooler and warmer, when we study the sections on heat and temperature.

A little watching of clouds will show us that we may divide them roughly into classes by their form. Ascending currents of moist air cool, condense, and roll up mountainous masses of cloud, having a height of thousands of feet or sometimes of several miles. Whether large or small, they are known as *cumulus* clouds. Their bases are horizontal, and mark the level at which the rising air is cooled to the dew-point so that condensation begins. Great cumulus clouds, growing rapidly in height, are often seen in summer in connection with thunder-storms. Tangled and feathery, delicate and plume-like clouds are called *cirrus*. They are the highest clouds, usually from 5 to 10 miles above the sea-level, and they are thin, obstructing but slightly the passage of the sun's rays. Any widely spread cloud mass from which rain or snow is falling may be called *nimbus*, and the name *stratus* is sometimes applied to horizontal layers of cloud.

Rain and snow. — Everything that moves through the air rouses a resistance called friction. Heavy bodies are less checked by this friction than light bodies. The minute water particles forming clouds, like the particles of fine dust, have so little weight that their falling is exceedingly slow, and we say they float in the air. If the condensation that made them is carried farther, they grow larger, fall faster, gather still more moisture as they descend through moist air, and come down as *rain.*

If condensation takes place in a region whose temperature is below the freezing-point, the moisture gathers into crystals of ice of various forms, and these fall as *snow.* Flakes of snow are related to drops of rain as hoar frost is to dew. When a cloud in which rain-drops are forming is at the same time cooled below 32°, the drops are frozen to ice pellets. Sometimes these pellets, by falling through freezing rain, or rain and snow, gather more ice and become *hailstones,* and these are often large enough to reach the earth without melting.

Rainfall. — This term is applied to all descent of water to the earth's surface, whether as rain, snow, or hail. It relates to the quantity of the downfall. The word *precipitation* is also used in this sense. When snow falls in still weather, it makes an even layer on the ground, and we may measure its depth in inches or feet. But as snow may be wet and heavy or dry and light, such measurement does not tell how much water the snow represents. Therefore, for exactness, the snow resting on a definite space — a square foot, for example — is melted, and the resulting water is measured. To learn the amount of rain which falls, a vessel like a bucket, with straight sides, is placed out of doors, and after each rain the depth of the water caught in it is measured. The quantity of rainfall at any place, or in any time, is expressed in inches of depth.

The map of Canada in Fig. 113 shows by lines the

amount of rainfall during a year in different parts. The map should be carefully studied, not only because of the information it gives about rain, but because it is an example of an important mode of combining many facts into a sort of picture easily understood. Such a map is said to show the *geographic distribution* of rainfall.

A narrow belt along the sea on Vancouver Island and the northern coast of British Columbia receives more than 100

FIG. 113. — Geographic distribution of rainfall in Canada.

inches of rainfall in a year. The west winds from the warm Pacific, laden with vapour, are chilled to the dew-point as they begin their journey over the cooler land. Similar abundant rains occur along the Atlantic coast, the average in the Maritime Provinces being a little more than 40 inches, while on the south-west coast of Nova Scotia it is about 55 inches.

On the other hand, in southern Alberta and the Kamloops region of British Columbia the rainfall is not more than 12 inches a year. The southern region of Alberta passes into a wider belt towards the east, in Saskatchewan and Manitoba, where the rainfall is from 18 to 22 inches a year. The damp air from the ocean loses much of its moisture in passing the mountains of the coastal belt,

especially at the north, and has little rain to distribute in the interior. The Rocky Mountains receive much more of this remnant than the plateaus on either side.

In southern California and northern Mexico the arid region extends to the very coast of the Pacific Ocean, the explanation being found in the comparative warmth of the land as compared to the ocean. This leads to the principle that mere nearness to the ocean does not cause abundant rain unless the air from the ocean grows cooler in crossing the land. If the ocean is cooler than the adjacent land, then whatever winds blow from ocean to land have their capacity for moisture increased by warming, and instead of dropping rain, drink up any water they find.

The northern prairie region of the United States receives a medium amount of rain. It has enough to support abundant vegetation, but less than the regions adjoining the Gulf of Mexico or either ocean. This brings out another great principle, that rainfall is less abundant in the interior of continents than it is upon their borders. Such lands are farther from the source of supply.

If we go south we shall find very great rainfall in some parts of Central America, and in the northern, central, and eastern parts of South America. Much of the Amazon country receives over 80 inches. The prevailing winds from the warmest part of the Atlantic explain this condition, which is the great exception to the rule of small rainfall in the centres of continents. As a rule, rains are more abundant in the tropical latitudes, but there are exceptions to this principle, as some parts of South America, west of the Andes, are very dry. In polar latitudes the rainfall (mainly as snow) is less than in temperate and tropical regions, because these regions are too cold for much water to be evaporated from the seas.

The rainfall of Great Britain and Ireland (Fig. 114) gives

us an interesting parallel, on a small scale, with western North America. The moisture-bearing winds come from the Atlantic, and the western coasts have 40 inches of rainfall, with 60 to 80 inches on the highlands, but the central and eastern plains have only 25 to 30 inches. In a hot region 25 inches of rain would be a meagre supply for farm or garden, but in the cool climate of England it is ample. As we go eastwards over the plains of Europe, we find the rainfall gradually less, and much of Russia is arid — further illustrating the principle that the interior of a continent is drier than its borders. In southern Europe, the Alps receive abundant moisture, brought by warm winds from the evaporating surface of the Mediterranean.

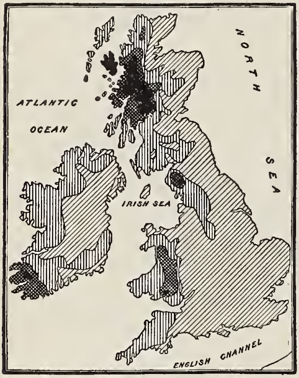


Fig. 114. — Rainfall map of the British islands. The country with more than 20 and less than 40 inches is shaded by oblique lines; that with between 40 and 60 inches, by vertical parallel lines; with between 60 and 80 inches by crossed lines; with more than 80 inches, by solid black.

The rainfall of Asia shows the usual contrasts between the sea border and interior, and between tropical and arctic latitudes. Thus, in India and Burma, the southwest monsoons from the Indian Ocean bring great rains, and southern Asia is well watered up to the Himalaya Mountains. Amid their cold heights the moisture which has been successfully carried over the plains of India is condensed, and the high plateaus of Tibet and of central Asia in general are a desert. Southern Siberia receives moderate rainfall, but the north is dry, even though bor-

dering the Arctic Sea, for the reason already stated, that little evaporation can take place where winter continues for most of the year.

Eastern Asia has a plentiful supply of rain. Japan has a rainy season lasting most of the time from April

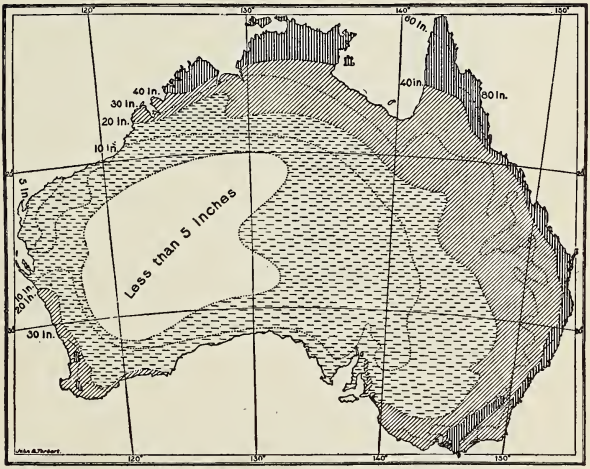


Fig. 115. — Rainfall map of Australia. Dotted lines run through points of equa-rainfall. The country with more than 5 and less than 20 inches rainfall is shaded by broken horizontal lines ; that with between 20 and 40 inches, by oblique lines; with more than 40 inches, by vertical lines.

until September. The average fall at Tokio is 58 inches. This resembles in abundance that of western British Columbia and the Nova Scotia coast. At the capital of Korea the rainfall averages 36 inches, but at Hong Kong, much farther south and directly affected by the sea, the amount is 78 inches. Similarly heavy is the rainfall of the Philippine Islands and the Dutch East Indies. The most wonderful rainfall in the world is found where the

monsoon winds from the Indian Ocean send down their moisture upon the delta region of the Ganges, resulting in an average fall of 500 inches a year, and amounting in one exceptional year to 800 inches, which, if it could have remained on the surface, would have formed a sea 67 feet deep.

Australia (Fig. 115) has an enormous interior area with rainfall of less than 10 inches. In a general way, this increases towards the shore line, though parts of the south and west coast are dry. The north and east coast areas have from 30 up to 50 inches or more. We still find our principle of a dry interior and a wet border true for the great lands.

The largest dry area in the world is the Sahara of North Africa. The general movement of air across it is from the Mediterranean at the north, and this air, passing from a relatively cool ocean to a very warm land, refuses to give up its water. The same principle controls as in southern California.

Light and Colour

Light. — The light which comes to us from the sun travels in a straight line, and with such wonderful speed that it reaches the earth in about eight minutes. It is white, and we commonly say it is without colour; but the absence of colour is really black, and white is the sum of all colours. A beam of white sunlight is made up of a great number of variously coloured rays — red, orange, yellow, green, blue, violet. The full understanding of the nature of light belongs to the subject of physics, but we need to know a few of its properties, in order to study the sky intelligently.

There are three ways in which white light is divided into the colours which compose it: (1) When it falls on an object which is neither white nor black, some of the rays

are absorbed and disappear while others are *reflected.* Thus grass reflects the green rays and a lemon the yellow rays. (2) When sunlight passes from one transparent substance to another, its rays are usually bent or *refracted,* and some rays are bent more than others. Thus if a narrow beam of light is allowed to pass through a glass prism to a sheet of white paper, the red rays reach the paper in one place, the yellow in another, the blue in another, and we have a beautiful series of colour-bands. (3) And when light is sifted through a thin cloud of very fine particles it is scattered by *diffraction,* the several colours being differently affected and thus separated. Nearly all the beautiful and infinitely varied colours of nature are produced in some one of these ways.

Colours of the sky. — We have already learned that the atmosphere carries small particles picked up by the wind. The finest of these are so minute as to be invisible; they float so high as to be above all rain and are never washed out. Their existence is known only by their effect on sunlight, which they scatter enough to give colour to the sky. Without the dust a cloudless sky would be black. With it all the upper part is blue, changing to pale gray near the sun and near the horizon, while at sunset and sunrise the blue grades downwards into rich yellow and rose, orange and red. Little wonder is it that the sky is thought by savage peoples to be a solid dome of crystal.

When the lower air contains coarser dust, or haze, all the colours become duller, and grays predominate; but what may be called water-dust — the minute particles of vapour at the edges of clouds — give at sunset the most intense of all sky colours. The great explosion of Krakatoa in 1883 sent an immense cloud of fine dust into the upper air, which gradually drifted and spread, intensifying the sunset effects wherever it went. Within a year it had covered the whole globe, and it settled from the air

so slowly that some of its effects were still visible three years later.

The rainbow. — This is an arch showing the colours given by the prism. It is seen where the sun shines on drops of falling water. It most often appears after a thunder-shower has passed, but on a small scale may be seen in the spray of a waterfall or even an artificial spray. In each drop of water the sun's rays are bent (refracted), turned back (reflected), and bent again, and the white light is broken up into its constituent colours. The rainbow is not seen in widely extended rains, because the clouds then cut off the sunlight.

A *halo* is a ring of light about the sun or moon, and is believed to be due to similar action of the light rays upon very small ice crystals, forming thin clouds in the upper regions.

Temperature of the Atmosphere

Measurement of temperature. — This is done more or less carefully by almost every one in civilized lands. The instrument is the *thermometer*. A small glass tube, of uniform size, has a bulb at one end which is filled with some liquid, usually mercury, which extends part way up the tube. If the mercury is warmed, it expands, some of it passes from the bulb to the tube, and the column of mercury in the tube grows longer. If the mercury is cooled, the column becomes shorter. Thus the position of the top of the column depends on the degree of warmth, or the *temperature*, of the mercury. To each thermometer a scale of parts is attached. English-speaking peoples use mainly what is known as the *Fahrenheit* scale, on which the temperature at which water freezes is marked as 32°, and the temperature at which water boils as 212°. In many other countries the *Centigrade* scale is used, in which 0° marks the freezing-point and

100° the boiling-point of water. As 180 degrees of one scale covers the same range as 100 degrees of the other, their degrees have not the same size. One degree of the Centigrade scale equals 1.8 degree of the Fahrenheit. In this book the Fahrenheit scale is used.

To measure the temperature of the air the thermometer is hung where it will not be affected by heat radiated from other objects, especially the sun and the human body, and is allowed to remain a few minutes until the air has had time to cool or warm the mercury to its own temperature. Then the top of the mercury column is compared with the scale, and the mark it stands nearest is noted. This is called *reading the thermometer* or *observing the temperature.*

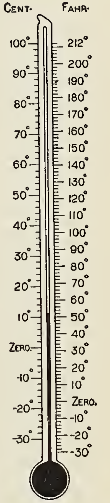


FIG. 116. — A thermometer with Fahrenheit and Centigrade scales.

Source of heat in the atmosphere. — We may neglect the small amount of heat that comes from the stars. So also we may leave out of account any heat from the earth's interior. The cold crust lets little heat come through, except locally in volcanic eruptions and hot springs. Practically all atmospheric warmth comes from the sun. As the earth is only a speck, far from the sun, and the sun blazes out in all directions, we receive only an inconceivably small fraction of the sun's total heat. But without it the earth would be a frozen, dark, and lifeless ball.

Modes of warming and cooling. — Place a brick on a hot stove. After it has been there a few minutes, lift it for a moment and feel the under surface. It is warm. It has become warm by receiving heat from the iron of the stove. You know that it is warm because it communicates heat to your hand. Such transfers of heat are

called *conduction.* Conduction may also take place within a body; leave the brick on the stove for an hour, and the heat will be conducted through it so that the top as well as the bottom will be hot. Now set the hot brick away from the stove, and then bring your hand near it. Without touching it you feel its heat. This is because the brick is losing heat by *radiation;* your hand receives some of its rays and is warmed. In time it will radiate away all the heat it gained from the stove and be as cool as the air about it. Try yet another experiment. Bring your hand near a block of ice. Your hand is cooled because it radiates heat to the ice. Take the ice in your hand and the hand soon becomes unpleasantly cold; the heat is now passing from it by conduction. All bodies have some heat, but there are differences in quantity. The important principle is that heat constantly tends to pass, by conduction and radiation, from warmer to cooler bodies. We are now ready to understand how the sun warms the atmosphere.

How the sun warms the atmosphere. — The sun's rays, falling all day on the ground and the ocean, warm them. The ground and ocean, because they are warm, radiate heat outwards. Both radiations pass through the air, and the air is warmed by them. The amount of heat received by the air directly is small, but the dust and cloud particles absorb heat more freely than the gases, and much that they receive is given to the air about them. The air is also warmed by contact with the warm ground.

At night the outward radiation by ground and ocean, cloud and dust, is not balanced by the sun's radiation, and there is a general cooling. The change in temperature from day to night and night to day is small in the upper air and greatest at the ground. So the ground at night usually cools the low-lying air instead of warming it.

Clouds intercept radiation whether from above or below. So when a dense canopy spans all the sky, the ground is little warmed in the day and little cooled at night, and the lower air, with which we are most concerned, undergoes little change. So, too, haze protects the ground and the lowest air from extreme changes; but the hazy air itself is warmed and cooled more than clear air would be. It is when the sky is clearest that we feel the greatest changes in the warmth of the air. In clear weather come the hottest days of summer, the

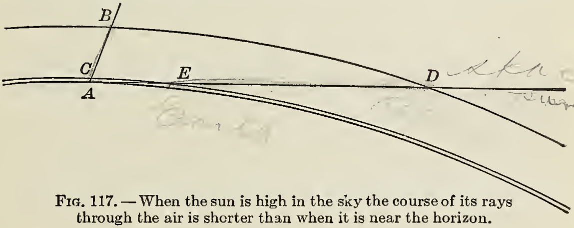


Fig. 117. — When the sun is high in the sky the course of its rays through the air is shorter than when it is near the horizon.

latest frosts of spring, and the earliest frosts of autumn. The sun's rays do not seem so warm in early morning and late afternoon as they do in the middle of the day; and, in fact, they carry less heat then, for they have lost more in passing through the air. Figure 117 shows this. The curve through *A* stands for the earth's surface, the curve close to it for the upper limit of clouds, and the upper curve for the outer limit of the atmosphere. Suppose we are at *A*. When the sun is low in the sky the rays that reach us pass through much more air (*D* to *A*) than when the sun is high (*B* to *A*); and the difference is still greater (*E* to *A*, compared with *C* to *A*) in respect to the denser air which absorbs most heat. In the warming of the ground there is another difference also, for a slanting beam spreads its warming effect over a larger

surface than a vertical beam of the same size (Fig. 118), and even if it had the same total amount of heat to bestow, could give less to each square foot of surface.

Temperature of day and night. — We have just seen that the sun warms the air most when it is highest in the sky, and that is at noon; but the warmest part of the day is usually several hours later. This is because heat is accumulated. The air about us is all the time receiving heat in various ways and all the time parting with it. So long as it gains more than it loses, the temperature rises; when it loses more than it gains, the temperature falls. On ordinary days the temperature begins to rise just after sunrise, and rises most rapidly in the middle of the forenoon. It stands highest at about two or three o'clock, and then falls through the remainder of the day and all the night.

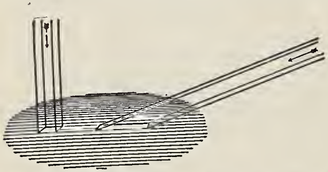


Fig. 118. — The influence of a slanting beam is spread over a larger area than that of a vertical beam.

Hang a thermometer in some convenient place out of doors, where it will be in shadow all the time, and then take a reading every hour. Rule a sheet of paper, as in Fig. 119, with two sets of lines. Make each vertical line stand for a particular hour and each horizontal line for a particular degree of temperature, and mark them with figures at top and side. Suppose your first reading in the morning is at six o'clock and you find the temperature to be 24°. Make a dot on the paper where the line for 6 A.M. is crossed by the line for 24°. At seven o'clock you may find the temperature 23°, and at eight o'clock 26°. Make the dots at the proper places, and connect each dot with the next one by a line. At the end of the day you will have a record of the temperature. In the

figure the record is complete for twenty-four hours. Such a record, by means of a rising and falling line, is called a *curve of temperature.* The upward swing in the afternoon shows the warmest part of the day; the

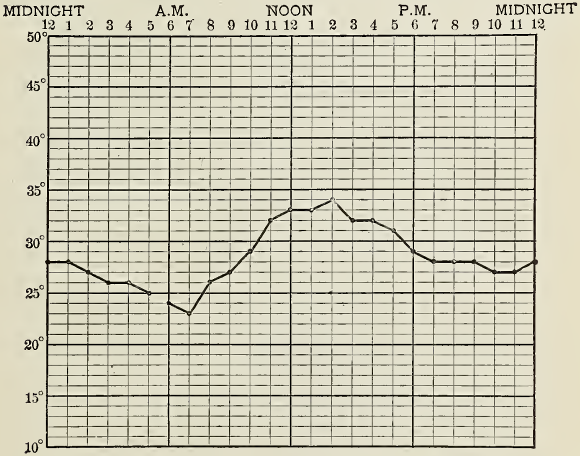


FIG. 119.—A thermometer record for a complete day.

downward swing, near morning, shows the coldest part of the night. Not all days yield the same kind of record. Clouds may interfere with the warming of the air or with its cooling, or winds may bring warmer or cooler air from some other place.

Temperature and latitude. — Let us think of the earth at one of the equinoxes* when day and night are equal in all the zones, for these positions represent the average for the whole year. In tropical latitudes the midday rays come directly down through the air and have their greatest heating power; in temperate regions they come slanting to the ground and are less effective; and in polar

* See page 308

regions their direction is still less favourable. So tropical lands and seas are very warm, polar regions are very cold, and there is a gradual transition from tropical warmth to polar cold. It is true that in another part of the year the northern hemisphere, for example, is tipped towards the sun and receives more heat; but this advantage is exactly balanced by a disadvantage six months later. The tipping causes the yearly procession of the seasons, but does not affect the average or, as it is called, *mean* temperature.

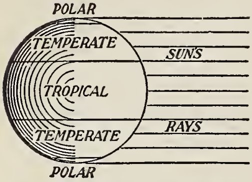


Fig. 120. — Relation of the great zones of the earth to the sun's rays in March and September.

The normal or average curves of temperature for the

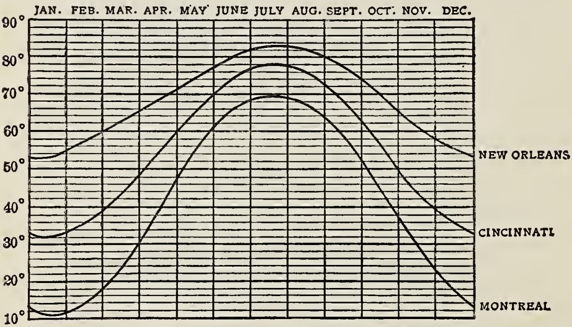


Fig. 121. — Annual curves of temperature for New Orleans (lat. 30°), Cincinnati (lat. 39°), and Montreal (lat. 45° 30′).

year at three cities are given in Fig. 121. The curve showing the observations for a single year would not be smooth, but very irregular, going up and down steeply for each day and night, and for all the warm and cold periods. Note the differences due to latitude; also that

Montreal shows the greatest change from winter to summer. This is because it is farthest from the equator, and away from the tempering waters of the sea.

Temperature affected by winds and currents. — We have seen that the day and night changes of temperature are not always the same. Nor does latitude tell us with certainty the amount of heat which the air will contain at a given place. Great winds, either steady or in transient storms, sweep volumes of warm air into cold regions, or masses of cold air into warmer places, and thus cause great and often sudden variations, as when a warm interval in winter or summer is followed by a sudden drop of 20°, 30°, or 40° in the temperature. Such changes will be explained in the following chapter. Ocean currents also, like the Gulf Stream, transfer great quantities of warm or cold water across thousands of miles of latitude, and change thus the amount of heat in the overlying air.

Temperature affected by land and water. — Earth and rock are not penetrated by the sun's rays. The daily warming and nightly cooling extend but a few inches into the ground. Even the accumulated heat of summer does not penetrate many feet. But water allows the rays to enter freely to some scores or hundreds of feet in depth, and through all this space receives heat. The sea warms less rapidly than the land, but when warmed retains heat longer. Hence the temperatures are less extreme and less exposed to sudden change on water than on land. The winter voyager on the ocean often encounters but a moderate degree of cold. Thus we can understand why the climate is more mild in the autumn in the presence of large lakes. Frosts hold off so long as the body of warm water is giving forth the heat accumulated in the summer. This is one of the reasons why the lake regions of south-western Ontario are favourable for the raising

of fruits. But as the cold becomes intense, the surface waters are chilled, grow dense, and sink to the bottom, until at length the waters as a whole have lost much heat, and the smaller or more shallow lakes are frozen over.

Temperature affected by altitude. — Illustrations of increasing cold and changing plant growth have already been given in our study of mountains. As a rule the temperature decreases about 1° for every 300 feet of altitude. Two experiments will help to explain this. Fill a bicycle tire by means of an ordinary bicycle pump. Then feel the pump cylinder and the tire. The cylinder is warm, especially at the end where the air has been compressed, and the tire is also warm. This means that the air has been warmed by compression. Wait until the tire has cooled to the temperature of the surrounding air; then open the valve and let the air in the tire escape. As it blows on your hand you feel that it is cold. It has been cooled by expansion. The general principle is that air and other gases grow warm when they are crowded into less space, and grow cool when they push apart so as to occupy more space.

As we shall presently see, the air has many motions. Some of them are horizontal, others up and down. When a body of air goes down, it is subject to more pressure and the compression warms it; when air goes up, it is partly relieved of pressure, and its expansion cools it. Thus the changes, back and forth, between higher and lower parts of the atmosphere keep the lowlands warmer than the uplands and give to the loftiest peaks perpetual frost.

The mapping of temperature. Isotherms. — We shall see, as we go on, that it is important to record the temperature of many places on a map, so that the distribution of heat over large regions may be seen at a glance. This is accomplished by having reports of thermometer

readings at a given time sent in by telegraph from hundreds of observers in different parts of the country. These temperature figures are written on the map in their proper places. Lines are now drawn through places having equal temperatures. Such lines are called *isotherms*, meaning "equal heat." This will be best understood by examining the temperature maps of Canada for January and July, 1904, as shown in Figures 122 and 123. These maps should be studied thoroughly, each isotherm being carefully followed, as they explain the principle of all temperature maps.

The student will now be ready to study three maps showing mean temperatures for the world. Figure 124 shows the isotherms for January. This means that all possible observations on land and sea have been taken into account, averaged for each locality, and the lines drawn through points of equal mean temperature. Figure 125 shows the same for July, and Fig. 126 for the entire year. It will not be possible to point out all that may be learned from a study of these charts, but some of the more important facts are as follows:—

(1) The isotherms run in general east and west directions around the globe, like parallels of latitude, but in curved instead of straight lines.

(2) Sometimes the curves are strong, showing that differences of land and water change the amount of heat that would otherwise be present. Thus the January isotherms run far north in the Atlantic.

(3) The isotherms are more regular in the southern hemisphere, because there the almost continuous water gives a more even temperature.

(4) In passing from north to south, in any longitude, the temperatures met are first higher and higher, and then lower and lower; at some point a highest temperature is passed. The line connecting all such points is

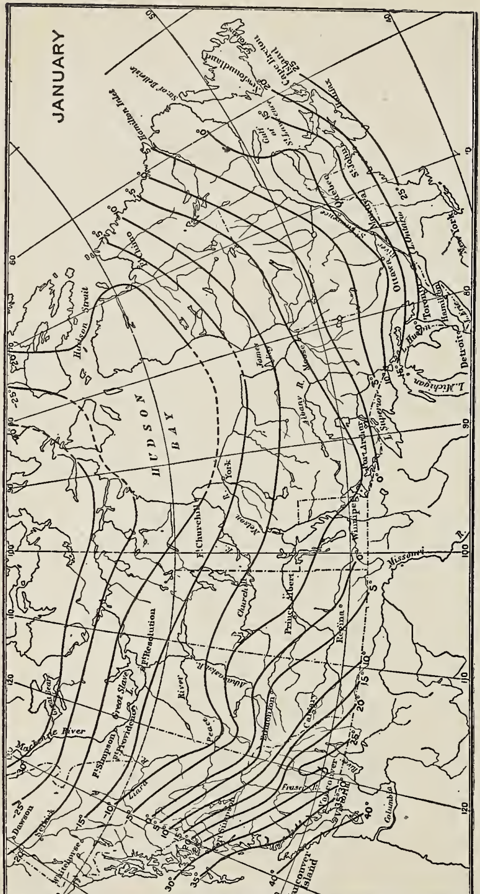


FIG. 122.—Isotherms for January, Canada.

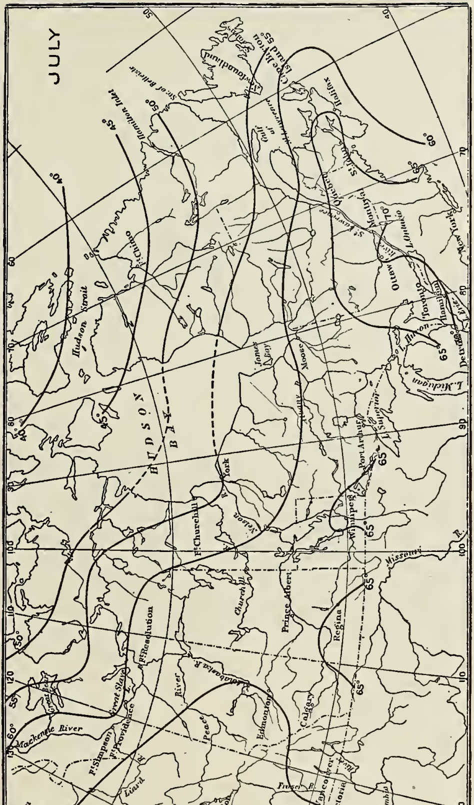


FIG. 123. — Isotherms for July, Canada.

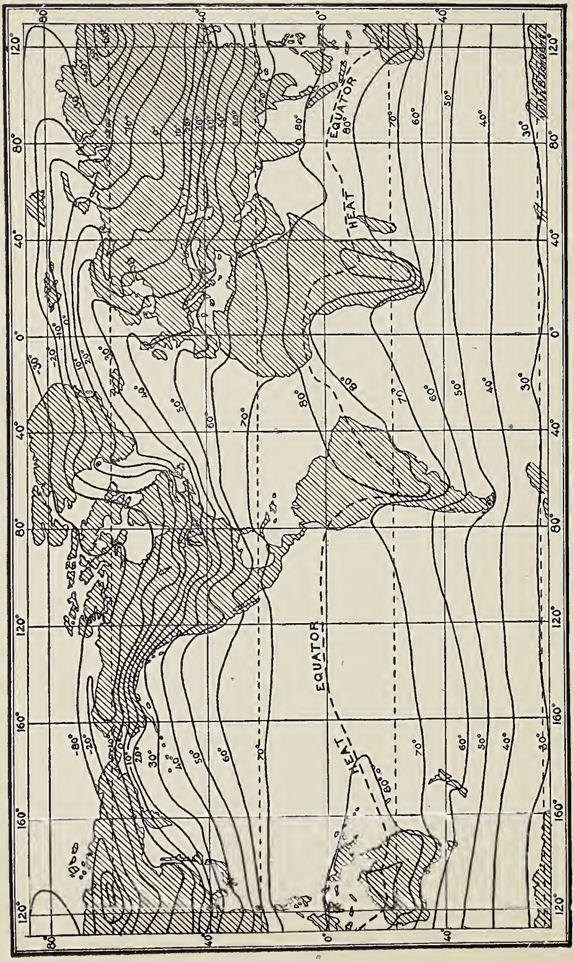


FIG. 124. — Isotherms and heat equator for January.

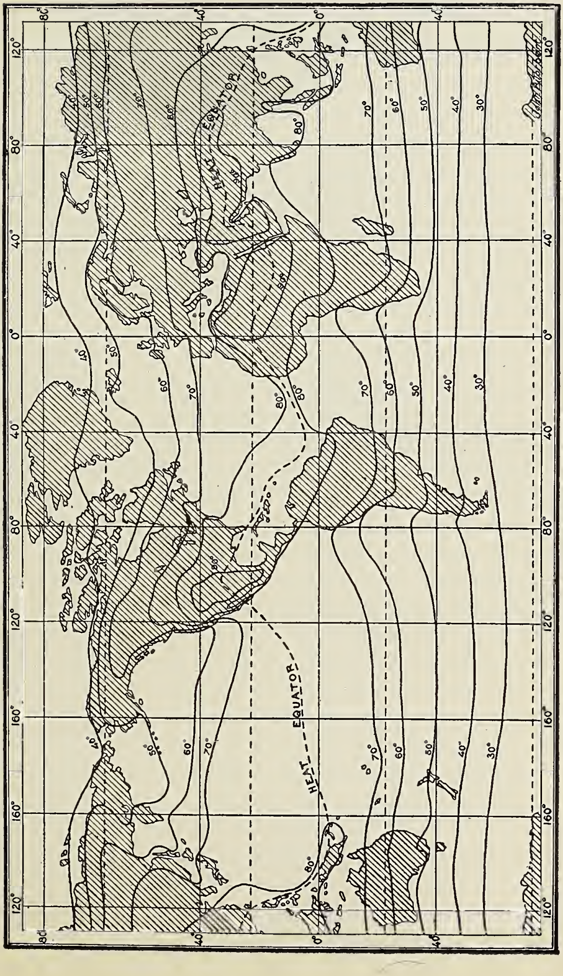


Fig. 125. — Isotherms and heat equator for July.

called the *heat equator*. It is a curved line and does not closely follow the geographic equator.

(5) In January all the isotherms in both hemispheres, and the heat equator also, are farther south than in July. The lines sway to and fro with the sun.

One thing which the maps do not show is the variation of temperature according to height. Whenever the record gave the readings on a mountain or plateau, a certain amount was added, so as to obtain the corresponding temperature at the level of the sea, and the sea-level temperature was used in making the map.

The Mercator projection.—Our maps of the world's isotherms show nearly the whole of the earth's surface, but are square-cornered instead of being round. The skin of an orange, or any large piece of it, cannot be made to lie out flat without stretching some parts. For the same reason a map of the round earth cannot be drawn on flat paper without giving some parts the wrong size or wrong shape. In trying to make this unavoidable error as small as possible, geographers have contrived several different ways of drawing maps, each one being best for some particular use. The arrangements are called *projections*, and have separate names. The map in Fig. 126 is drawn on the *Mercator projection*. Imagine the surface of the earth to be divided along a meridian and thus unrolled into a sheet, with the equator in the middle and the polar parts at the edges. All except a belt near the equator must of course be stretched, the amount of stretching being greater at a distance from the equator than near it. Thus, in Fig. 126 the parallel of 80° is as long as the equator, although on a globe it is less than one-fifth as long; and Greenland seems larger than Australia, though really much smaller. This projection is useful when we wish to bring all sides of the earth, except the poles, into one view.

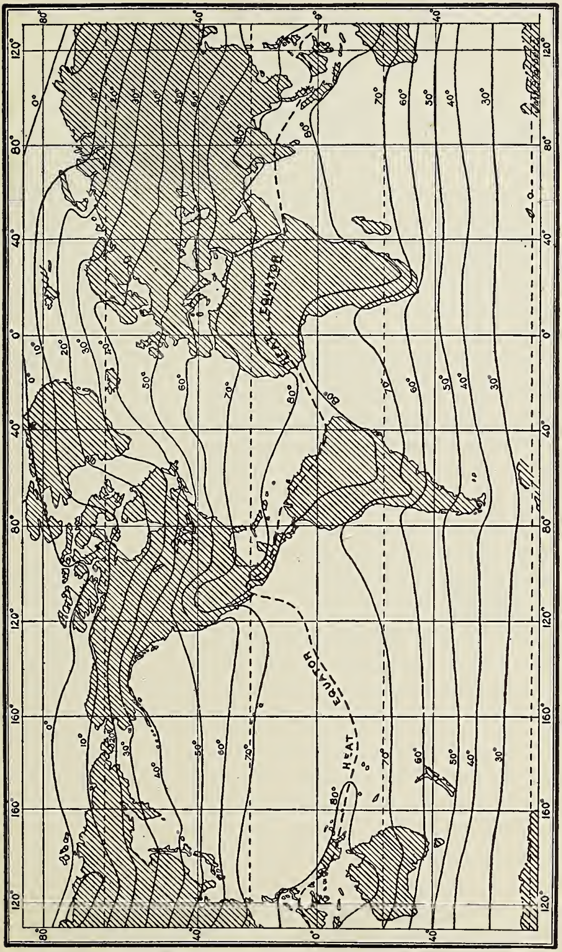


Fig. 126.—Isotherms and heat equator for the year.

CHAPTER XI

WINDS, STORMS, AND CLIMATE

THIS chapter will deal especially with the movements of the atmosphere. We have seen how the air is made up, and have studied some of its relations to moisture, light, and heat, but before we can understand its movements we must know it in another way — as regards its pressure.

Pressure of the atmosphere. —The atmosphere presses downwards, and its pressure is greater at low levels than at high. This pressure depends on the weight of the air, and varies somewhat in amount at any place as the temperature or moisture of the air is changed. The ordinary or mean pressure is called the *normal pressure*. The normal pressure at the level of the sea is about 15 pounds on each square inch of surface.

We can tell in a rough way how warm or cold it is by our sensations, but we know nothing thus of the amount of pressure which the air exerts in its different conditions, except, as has been said, at great heights. We measure the pressure by means of instruments called *barometers*. One kind of barometer is made with mercury and a glass tube. The glass tube, which must be nearly a yard long and closed at one end (B in Fig. 127), is filled with mercury, and then inverted with the open end in a basin of mercury, care being taken to admit no air in the tube. The mercury does not all run down into the basin, but only part of it; the rest stands in the tube, with an empty space (n to B) above it. The atmosphere presses on the mercury in the basin, but there is nothing to press on the mercury

in the tube. The mercury stands just high enough in the tube for its weight to balance the pressure of the air on the outside mercury. If the air pressure increases or diminishes, the column of mercury grows longer or shorter, and its length therefore measures the pressure. At sea-level the normal height of the mercury column in the barometer is 30 inches. For brevity we commonly say that the pressure of the air at sea-level is 30 inches.

If we carry the instrument up a mountainside, the top of the column will settle about one inch for each 900 feet of ascent. Hence it is that the barometer may be used for ascertaining altitude, when carried in a short time from one point to a higher position. As the mercurial barometer is heavy and inconvenient to carry, another instrument, called the *aneroid* barometer, is more often used for this purpose.

FIG. 127. — The barometer tube and mercury. In the complete instrument a scale of inches stands beside the tube, the zero of the scale being at the level of the mercury surface outside the tube.

Maps showing atmospheric pressures. Isobars. — As in the case of temperature, so with pressure, it is important to know the condition not only at one point but at many. It is convenient to record the figures for pressure at the respective points on a map. We shall best understand by taking a real case, and will choose January 7, 1886, at 7 A.M. The atmospheric pressures for all stations then reporting in North America were first put down on a map. Then lines were drawn through all points having the same pressure. In the case of pressure, one-

tenth of an inch is an important variation, and the map was arranged to show differences of this amount. These lines, called *isobars*, are shown in Fig. 128. Let the student observe that there is a belt of normal pressure, marked by the isobar of 30 inches, running from New York southwards to the Carolinas. Other isobars, for 29.9, 29.8, etc., appear to the eastward or to the north-east until in Nova Scotia we find 29.2, and the region is marked as having *low pressure*.

To the west of the isobar of 30 inches, we see that the lines swing around to the west and run across the continent, with higher and higher pressures in the north-west, until the last isobar curves around the south side of an area marked *high*, in Montana, Alberta, and Saskatchewan. The pressure there is 30.8 inches. Curving across the southern United States is another isobar for 30 inches, and south of that the pressure diminishes until, in southern Texas and Mexico, we find another area marked low, but still 0.6 of an inch higher than the low area of Nova Scotia.

Thus we find, on the morning of January 7, 1886, one area of high pressure and two of low pressure. In the intermediate regions the pressure is also intermediate. The most important contrast is between the north-east and the north-west, ranging from 29.2 up to 30.8 inches.

All these pressures are supposed to be measured at sea-level. In the interior of the continent the barometers used are actually several thousand feet above sea-level, but an allowance has been made in each case for the loss of pressure due to height, and the pressure marked on the map is that which would have been found if the barometer had been carried down a deep well to the level of the sea and there read.

The condition of the air continually changes, and the map we have just studied represents the temperatures

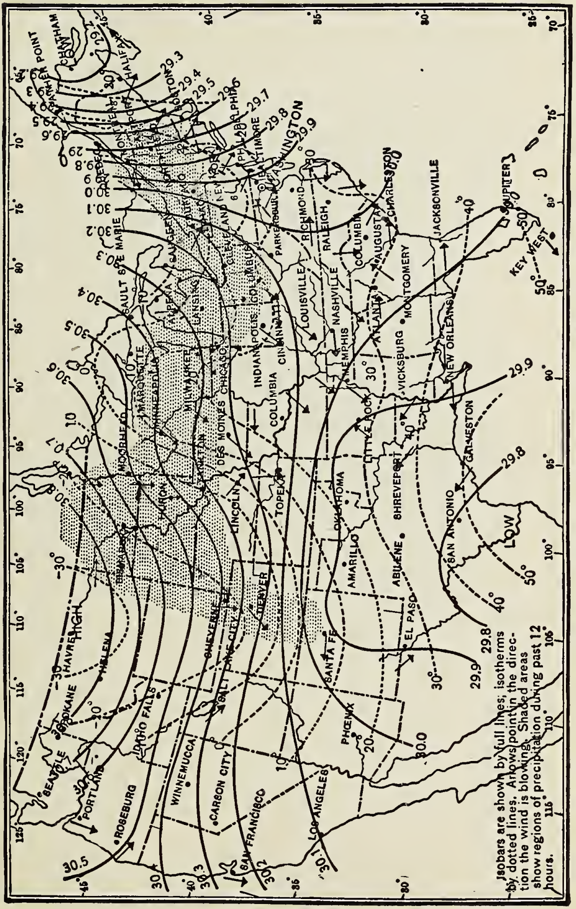


FIG. 128. — Weather map for the morning of January 7, 1886.

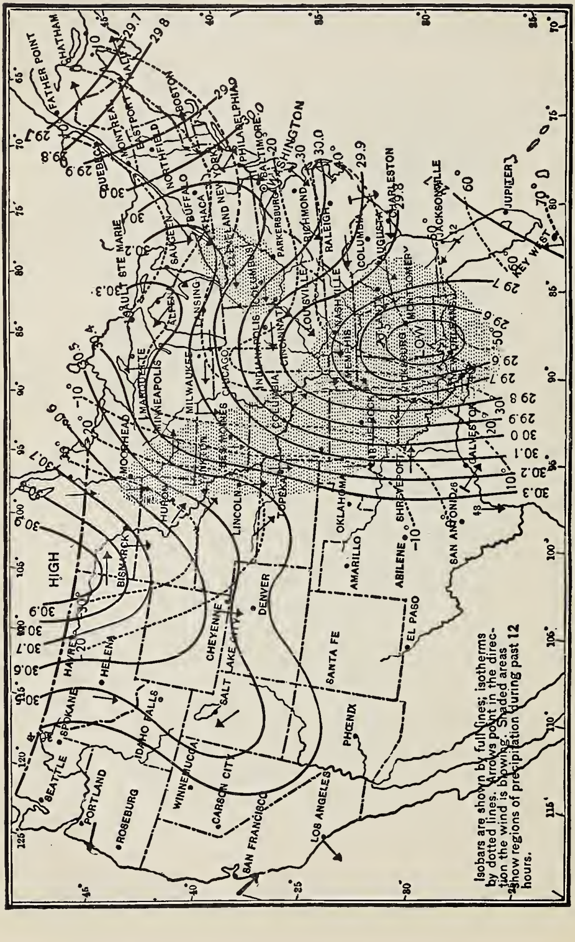
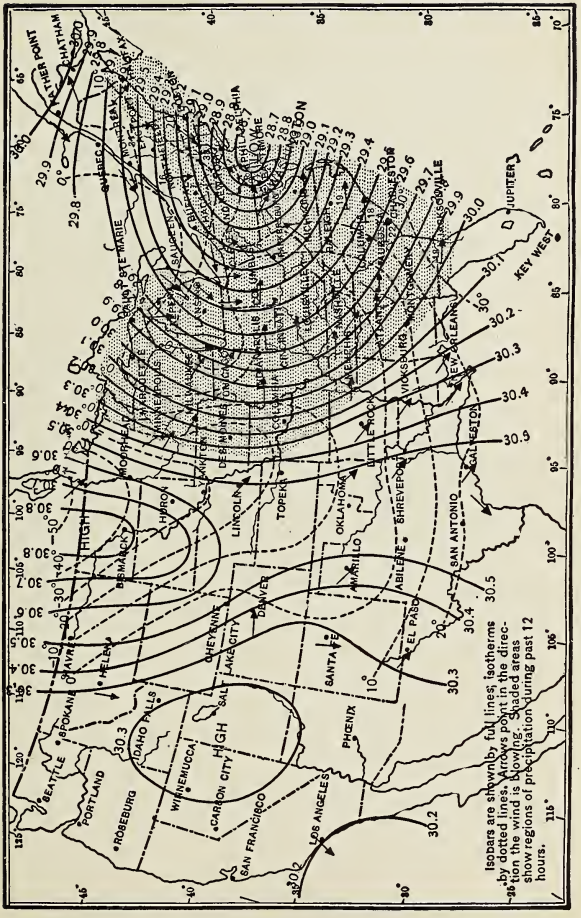


Fig. 129. — Weather map for the morning of January 8, 1886.



Isobars are shown by full lines; isotherms by dotted lines. Arrows point in the direction the wind is blowing. Shaded areas show regions of precipitation during past 12 hours.

FIG. 130.—Weather map for the morning of January 9, 1886.

and pressures only for a single part of one day. This will be plain if we now look at a map for twenty-four hours later, 7 A.M., January 8, 1886 (Fig. 128). The student must remember that continuous lines represent the belts of equal pressure, and for the present should neglect the other symbols of the map. The high-pressure area has moved eastwards and is in Saskatchewan, and the figure is 30.9 instead of 30.8. Pressure is still low in Nova Scotia but has slightly increased, being 29.7 instead of 29.6. The greatest change is seen in the south, where a well-developed centre of low pressure appears on the Gulf coast, the lowest isobar marking 29.5.

Again, let us study the pressures one day later, January 9 (Fig. 130). The high-pressure area has slowly moved eastwards and is in central North Dakota and Manitoba. A subordinate centre of high, but not very high, pressure (30.3) has developed in Utah, Nevada, and Idaho. The great Gulf centre of low pressure has moved far up to the north-east, being central in New Jersey, with a pressure of only 28.7. Varying pressure in any one place, and a moving to and fro of centres and belts of high and low pressure — these are the principles emphasized at this point.

Winds. — Let us turn again to our series of maps, taking first Fig. 128. The arrows show the direction towards which the wind blows, as reported by different observers on the morning of January 7. In the east they point *towards* the centre of low pressure. In the west they are more scattering because reports are fewer, but they are pointing *away from* the centres of high pressure. This is a general law, that winds blow from regions of greater pressure to those of less. If a fire is built in a stove which stands in a large cold room, the region around and above the stove is warmed, and its air becomes less dense; it therefore is a region of low pressure, and the

colder, heavier air from the sides crowds in and displaces the warm air, which is thus forced upwards. The draft towards the stove, whether strong enough to be felt or not, illustrates the origin of winds. They are sidewise movements by which the heavier air from centres or regions of high pressure is rushing towards the regions of low pressure. There are always winds blowing somewhere, and winds blow at frequent intervals everywhere, because something is always taking place to cause unequal pressure. Heat comes into and goes out from the air, through the succession of day and night, by the changes of seasons, and in regions of varying height and varying moisture. The atmosphere is a sea of gas, now at rest, now in gentle motion, and now tumultuous like the ocean in a storm.

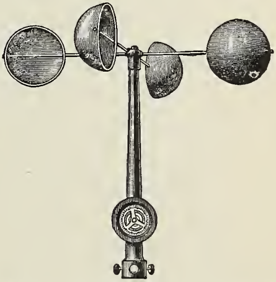


FIG. 131. — The anemometer. Inside the upright is a spindle to which the cross-bars are fastened. The wind pushes harder against the hollows of the cups than against the outsides, and thus turns the spindle. The stronger the wind, the faster the spindle whirls. A counting machine below is worked by the spindle and makes a record.

One further statement should be made about this general principle of wind formation. If the centres of high and low pressure are comparatively close together, the rush from one to the other is powerful and the wind has high velocity. In such case the isobars lie close together. The technical way of putting it is that the pressure slope or *gradient* is steep. The velocity of winds is stated in miles an hour. Under 10 miles we may call a wind a breeze. A strong wind has a rate of 20 to 30 miles, 40 to 50 miles marks a gale, and a hurricane has still higher speed. The direction of the wind is deter-

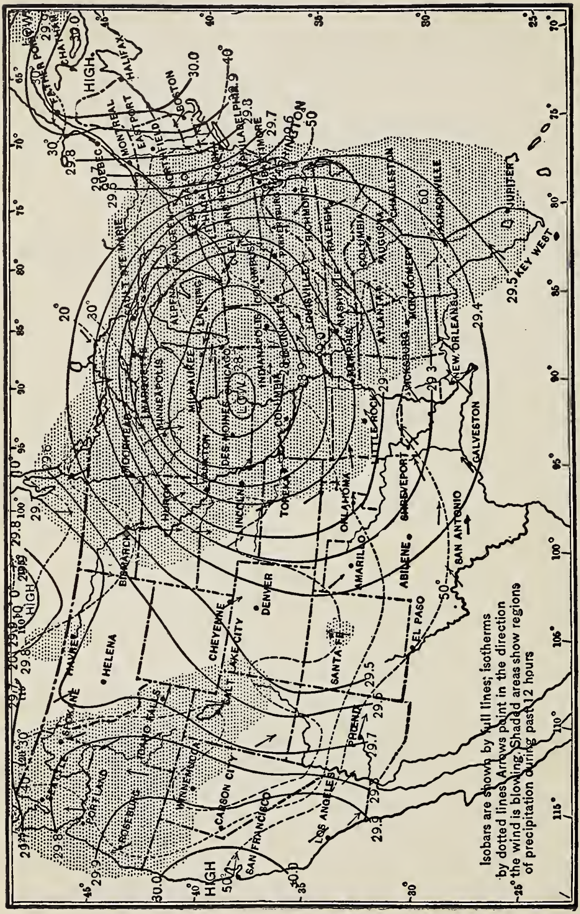


FIG. 132. — A cyclone storm for the morning of February 28, 1902.

mined, if accuracy is desired, by a *wind vane*, and the velocity is measured by an instrument known as an *anemometer* (Fig. 131).

Prevailing westerly winds. — In the middle latitudes of both northern and southern hemispheres, the winds more often come from the west than from any other direction. This is true to some extent even farther north and south. These winds are often briefly mentioned as the *prevailing westerlies*. We do not now ask why more winds should come from the west, but observe that we have here one of the great parts of the atmospheric circulation of the planet. These winds blow more steadily in the southern hemisphere than in ours, because there is less interruption by lands. Sailing vessels readily go by the way of Cape of Good Hope, cross the South Pacific, and return by Cape Horn, while it is difficult, especially near Cape Horn, to make the voyage in the opposite direction.

Storms of the westerly winds, or cyclones. — These winds, especially in the northern middle zone, do not blow forever to the east without interruption. They break into vast whirls or spirals, something like a small whirlwind, excepting that the winds are not always swift, and the whirl may be several hundred or one thousand miles across. Figure 132 shows such a whirl in eastern North America. The winds are blowing towards the centre, not directly, but in a spiral way, and swinging around from right to left. As we may know from the inflow of the winds, this is a low-pressure area. It is partly a region of rain, as indicated by the shading. Low pressure, relatively high temperature, rain, and shifting winds characterize the region. It is a *cyclone* or *cyclonic storm*. This is the proper use of the word cyclone, and we should not apply it to the tornado.

Now this cyclonic whirl is not stationary, but moving, usually in an eastward or north-eastward direction. It

will be followed by a centre or area of high pressure, also steadily moving eastwards. In this case the winds flow spirally, but out from the centre. Such a whirl is called an *anticyclone.* It is associated with low temperature and clear skies. As the cyclone with its variable and warmer winds passes, the skies clear, the winds come from

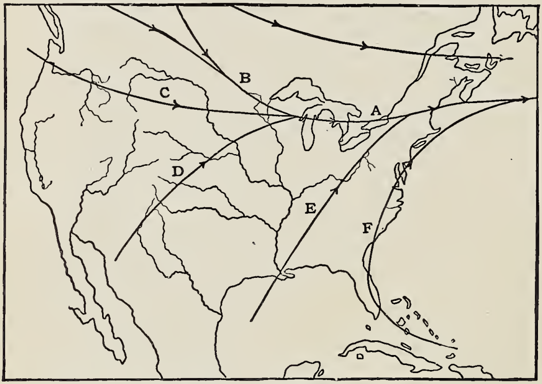


Fig. 133. — Paths usually followed by centres of cyclonic storms across the United States. Path *B* brings more storms than any other to the main track, *A*. Storms from the south-west (*D*, *E*) are comparatively mild. Tropical hurricanes follow path *F*.

the north-west, the anticyclonic whirl takes possession, and we say that a cold wave has come. We may again refer to Fig. 130. Observe the centre of low pressure on the Atlantic coast, the inflowing winds, the temperature of about 20°, and the great area of rain and snow stretching westwards beyond the Mississippi. The chief high-pressure area is on the United States border, the sky is clear, the winds flow out, and the temperature is very low. Thus the low and high areas follow each other across our continent. We may now understand why the temperature sometimes falls suddenly, 30° or 40° or even 50°. It

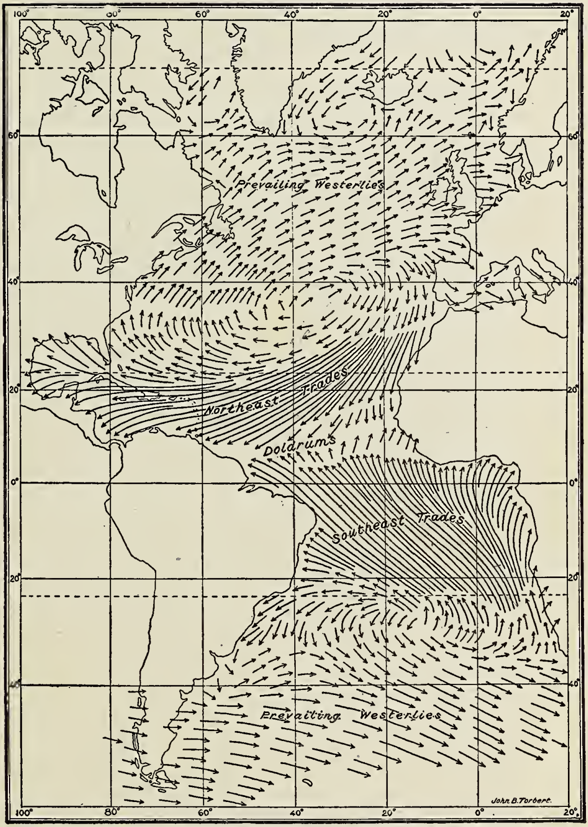


Fig. 134. — Winds of the Atlantic Ocean. The long arrows show directions of steady winds, the short arrows the prevailing directions of variable winds.

happens in the rear of a cyclonic storm. We shall have occasion to review these important facts in the section on weather prediction.

Trade-winds. — These are the most important movements of the atmosphere in the tropical and equatorial regions. They prevail in general to 28° north and south latitude. They blow obliquely towards the equator from the north-east and south-east. Thus there is a broad belt of north-east trades in the northern hemisphere, and a similar belt of south-east trades south of the equator. Their velocity is 10 to 30 miles an hour. They have received their name from the steadiness with which they flow. The trade-wind belt is usually clear, notwithstanding the winds blow over warm seas. The reason is that the air is moving from cooler to warmer regions and thus can hold more vapour without forming clouds. Between the northern and southern trades is a belt of calms. Here the moist, warm air of the trades rises to greater heights, is chilled, and sends down, almost daily, abundant rains. This region is called the *doldrums*. The Atlantic trades give up great quantities of moisture in equatorial South America, and up the eastern slope of the Andes. The west side of the range, however, as in Peru, is dry. Thus we see here the reverse of the conditions caused by the prevailing westerlies and the mountains of our Pacific coast.

Outside of the trade-wind belts in both hemispheres is a belt of calms and light winds, in which, however, the currents of air are descending. These regions are called the *horse latitudes*. Thus we have a great series of parallel wind belts. It is important to observe that the entire system of tropical and equatorial belts shifts somewhat northwards and southwards with the sun in the annual change of seasons.

Monsoons. — We shall define these winds by a description of the best illustration of them. They blow over

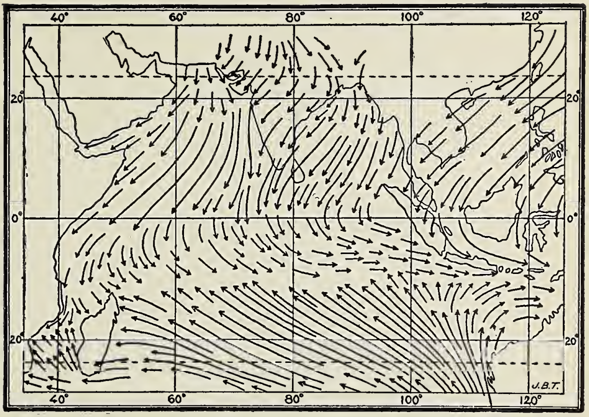


FIG. 135.—Winds of the Indian Ocean in January and February. The winds north of the equator are the North-east Monsoon, or Dry Monsoon.

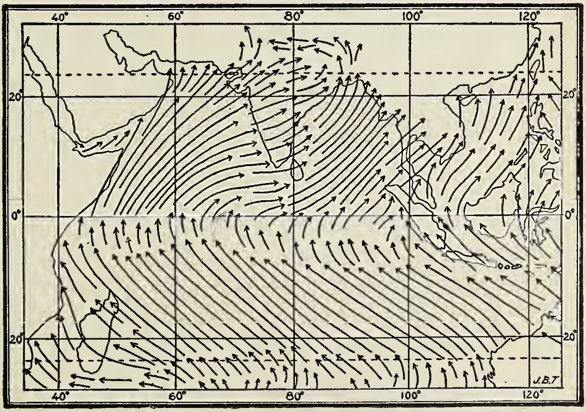


FIG. 136.—Winds of the Indian Ocean in July and August. The winds north of the equator are the South-west Monsoon, or Wet Monsoon.

southern Asia and the Indian Ocean. In the summer all the lands of India and central Asia become much heated. The expansion of the air makes its weight and pressure less than over the Indian Ocean. High pressure over the ocean and low pressure over the land cause winds towards the land, and they blow strongly and steadily all through the summer months (Fig. 136). The south-east trades swing around near the equator and blow from the south-west over southern Asia. To these winds are due the excessive rains and wet season of southern India. In the northern winter, on the other hand, the heat equator shifts southwards, the Asiatic lands are chilled, the air is cold and heavy, and the pressure is greater than above the ocean. Hence there is a rush from the land to the sea. The north-east trades now swing across the equator into the southern hemisphere (Fig. 135), and India has its dry season. These great periodical or seasonal winds are the *monsoons*. The arrangement of land and sea favours their development in this region.

Land and sea breezes. — These are not to be confused with monsoons, though they are like them in flowing now from the land and now from the water. They are light winds which spring up by day and night. As the land heats and cools more quickly than the sea, it often becomes warmer than the adjacent water during the day and cooler at night, and it communicates its temperature to the lower part of the air. So by day the air above the sea is the heavier and flows towards the land, and at night the cool air above the land flows towards the sea. The same changes may take place on the borders of lakes. These are daily changing breezes, therefore, while monsoons are steady winds changing with the seasons.

Day breezes and night calms.— The student has often noticed that considerable breezes may rise during a warm summer day, but that they usually subside towards even-

ing, leaving the air calm. During the day the air near the ground becomes much more heated than the upper air, owing to its receiving much heat by radiation from the earth. Hence the heavier air above sinks through the lighter air below and crowds it away here and there, causing sidewise movements or breezes. These movements cease when the sun's warmth is withdrawn.

Thunder-storms. — We have as yet studied but one kind of disturbance to which we give the name of storm — namely, the cyclone or broad spiral whirl, developing in connection with the westerly winds in middle latitudes. We now take up special kinds of storms, which are alike in that most of them are somewhat local and all are more or less sudden and violent. We take first the *thunder-storm.*

The student is familiar with the common character of such a storm. It usually occurs in warm latitudes or in the warm season of the temperate regions. It often follows a period of intense heat and usually occurs in the afternoon. It is heralded by the approach of large cumulus clouds from the west. A sharp breeze springs up, the sky is overspread, and rain pours down. After a short time, usually not above a half-hour, the rain ceases, the clouds move to the eastward, the sun shines, and a rainbow appears. The rapidly forming cumulus cloud marks a swift up-draft of heated air which expands because it rises, cools because it expands, and discharges rain because it cools. The lightning is due to the electricity generated in the clouds in their sudden formation. It is an electric spark, like other electric sparks except for its intensity and power. The thunder is caused by sharp vibrations set up in the atmosphere by the passage of electricity. It comes to us later because sound travels more slowly than light; it continues to roll because the sound from remote parts of the flash requires more time to reach us.

In the temperate latitudes the thunder-storm is usually associated with the cyclonic storm, and is most often reported as occurring some hundreds of miles south, south-east, or south-west of the cyclonic centre, or area of low pressure. Many thunder-storms occur near the equator, in the belt of calms, where the warm air is chilled by rising. These take a westerly direction. Thus tropical thunder-storms follow the trade-winds, and middle-latitude thunder-storms follow the eastward moving cyclones of the westerly winds.

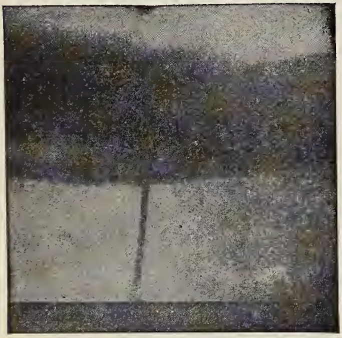


Fig. 137. — A waterspout; Vineyard Sound, August 19, 1896. From a photograph; copyrighted by Baldwin Coolidge.

Tornadoes. — These are violent, whirling disturbances arising, like thunder-storms, in connection with cyclones. A dark funnel-shaped cloud extends down to the earth with a swift, whirling motion, at the same time rushing swiftly over the land. The wind has such force as to destroy houses, uproot trees, and hurl men and animals for considerable distances through the air, but the path of destruction is narrow — only a few hundred yards wide. Such storms are often reported as cyclones, but this term should be reserved for the larger, less violent storms already described. A *tornado* at sea is called a *waterspout.*

Tropical hurricanes. — These are also called tropical cyclones, because, like the cyclones already described, they are whirling storms. The whirls are not so extensive as those of higher latitudes, but they may still have a diam-

eter of 300 miles or more, and the spirally blowing winds are much more violent, reaching velocities of 60 to 70 miles an hour. They start in the equatorial belt of calms and travel westwards. Those of the Atlantic often swing around and pass northwards over the West Indies and Gulf region and then bear to the north-east, off the eastern shores of the United States. These storms do not form on the land. Being always on the sea and of exceeding violence, they are most dangerous to ships. The spiral movement does not extend to the centre. There an area of calm is found 10 to 20 miles across, which is called the *eye of the storm.* Within it the sky is clear. Outside, but not far from this central area, the clouds are dense, often causing darkness, and heavy rains fall. The progress of such a storm occupies several days, and in some cases a number of weeks, traversing a very long track. Such storms in Oriental seas are known as *typhoons*. Destruction is very great when one of them moves over an inhabited island, or drives great sea waves upon the shores of a continent.

Origin of terrestrial winds. — The trade-winds and the prevailing westerlies, or broad currents from west to east in middle latitudes, belong to a great system of atmospheric movements, called *terrestrial,* because they pertain to the earth as a whole. Thunder-storms, tornadoes, and cyclones are local disturbances which temporarily interrupt the uniformity of the greater movements.

Two facts are fundamental to the explanation of terrestrial winds. First, the regions about the equator are much warmer than those nearer the poles. Hence the air is light and the pressure low, and the colder air from the north and south pushes in and crowds it up. Great volumes of warm air rise in the doldrum belt, spread out above, and flow towards the poles. Thus there is a great circulation of the atmosphere, towards the poles above, towards the equator below. In tropical regions these

lower currents sweep the surface of the earth, constituting the trade-winds, but in middle latitudes they flow higher, leaving space beneath them for still other currents, which follow the surface and tend polewards. The currents are shown in Fig. 138, where the outer band represents a section of the atmosphere.

Fig. 138.—The prevailing winds of the globe; with a section of the atmosphere showing its system of permanent currents.

The second great fact is the deflection or turning of air-currents by the earth's rotation. The rotation affects the direction of every body moving along or above the surface. In the northern hemisphere it makes moving bodies tend to curve towards the right, whatever the direction of their motion, and in the southern hemisphere towards the left. So the trade-winds north of the equator, being turned to the right of their southward course, flow towards the south-west; and the trade-winds south of the equator being turned to the left of their northward course, flow towards the north-west. In middle latitudes of the northern hemisphere the lowest or surface winds are turned to the right from their northward course and flow nearly east, and the corresponding winds of the southern hemisphere, being turned to the left from a southward course, also flow nearly east.

The prevailing winds at the surface of the earth are shown in the inner part of Fig. 138. All winds are named

after the direction *from* which they flow. So the trade-winds blowing towards the south-west are called the north-east trades, and the winds blowing towards the east in middle latitudes are called westerlies.

Weather and Climate

Weather. — This word refers to the state of the atmosphere. The atmosphere may be warm or cold, wet or dry, still or moving, cloudy or clear, and we therefore speak of the weather as hot, or sultry, or cold, or cloudy, or stormy, as the case may be. If the condition is stable for days or weeks, we speak of settled weather, or if it is changeable, we characterize the weather accordingly.

We not only speak of the weather and describe it fully in language, but we record it upon maps. Temperature is a weather element, and we record this by means of isotherms. Barometric pressure is another weather element, and we express this by isobars. In like manner arrows represent the direction of winds. Shaded areas tell where there is rain or snow, at the time for which the map is made. Other features may be shown, but these are the chief things.

Weather service and prediction. — For about thirty-three years the Canadian Government has maintained a weather service. It is in charge of the Meteorological Service, a part of the Department of Marine and Fisheries. Each morning at the same hour (eight o'clock in the East and five o'clock on the Pacific coast) observers record the various weather elements at their stations and send the results by telegraph to Toronto. A force of clerks receive the facts and record them on weather maps. From these maps experienced forecasters determine as nearly as possible what the weather will be, and the forecasts are sent to all parts of the country. The forecasts are widely published in newspapers, and special warnings are sent to sea-

ports, in order that shipmasters, knowing the coming of dangerous storms, may delay in putting to sea. The coastwise vessels of every kind greatly profit by the weather service. The coming of a tropical hurricane from the West Indies may be made known in the Maritime Provinces in time for protection of shipping and coastwise property. Stations are maintained along the Fraser and Thompson rivers, from which the data as to rainfall, melting of snow, and other changes are reported, and on these are based forecasts of damaging floods, so that property on low grounds may be removed and life be less endangered.

The principal predictions of the weather service are possible because of what is known of the direction and progress of the great cyclones or low areas, and of the behaviour of winds, of clouds, and rainfall in all parts of them. No two cyclones, indeed, are just alike, and some depart widely in rate or direction from the usual rate or course, so that mistakes may be made; but the service as a whole has demonstrated its value to the people of the country, and is sure to come to greater completeness and accuracy in the future.

Many supposed signs of the weather have no foundation in fact. Such are the aspects of the moon, and all sayings about the relations of certain days of the month or season to the weather that will follow. On the other hand, old observers of the weather know many true signs of wind, cloud, and sky, which give them shrewdness in prediction even when they are not able to explain or assign a cause. By long habit they recognize the usual order. But such foretelling could serve only for one locality, and could in no way take the place of the wide view provided by the Weather Bureau.

Climate. — The climate of a region is the sum of its weather. It includes the weather of the succession of

seasons for a succession of years. A year's weather follows the general course of all years for the special region, but may be quite peculiar in some respects. Thus in Ontario there is occasionally an "open" winter, or an exceptionally hot summer, or abnormally heavy snows. Hence a period of years is necessary for a full knowledge of climate. Like the weather, climate is described according to its most important or striking features. Thus it may be dry, wet, cold, temperate or hot, uniform or subject to great extremes. Or we may describe it by its relations to man, as healthful or the contrary, as bracing or enervating, as agreeable or unpleasant.

Climates of Canada. — We use the plural here, because our country covers so many degrees of latitude, ranges so far from coast to interior, and has such a variety of lowland and upland, that a variety of climates is the result. Southern Canada is within the Temperate zone, but part of the north of Canada is within the Arctic Circle, or has Arctic conditions, as in northern Labrador. The isotherms do not correspond to the parallels of latitude, but run diagonally in the north-west of Canada. The Pacific coast has a much milder climate in a given latitude than the Atlantic coast. The lofty Rocky Mountain region has a colder climate than the lower ground to the east or the west. The flanks of the mountains are still white with fresh snow, while flowers are blooming and cherries ripening near the Pacific.

A most important fact of climate in North America is the prevalence of the great cyclonic and anticyclonic storms, and a strong swing between winter and summer conditions. Thus in the summer the areas of low and high pressure follow each other across the continent from the west to the north-east, giving an alternation of warm waves and cooler spells. In winter these alternations are still stronger, giving us violent winter storms followed by cold

waves, with clear skies and zero temperatures. Only along the Pacific coast are the contrasts subdued by the presence of the ocean.

Almost as often as by heat and cold, we describe the climates of our country according to the amount of rainfall. Throughout the north, the winter precipitation is mainly in the form of snow. This being a poor conductor, keeps the ground from freezing as deeply as it otherwise would, serving as a blanket to retain the heat already received. On the other hand, the sun's heat is lost by reflection from its surface, and the winter cold is thus increased. All the eastern region is well watered. Over the prairies the rainfall diminishes, but is abundant for plants until we reach southern Alberta, where irrigation is desirable in some seasons.

Climates of other lands. — Space will not permit of any complete account of the climates of the world. In describing the distribution of rainfall and the winds and storms of the globe, much information has been given concerning climate. It is more important that the student should grasp the principles which control climate, than that he should here find a systematic account of climates. A restatement of some of these principles follows.

Difference in latitude, and the resulting differences in the amount of heat received from the sun, give us the basis for climate. The inclination of the earth's axis, causing the succession of seasons and an alternation of seasons in the two hemispheres, is the next great principle. The distribution of land and water introduces other great changes into the climates which latitude would give. This is strikingly seen in the North Atlantic, with its currents carrying warm water against the shores of the Gulf of Mexico, drifting thence upon the shores of Europe, giving mild climates in Great Britain and Germany, which have the latitude of Labrador. As a further principle, the

atmospheric circulation of the globe gives us the trade-wind climates of the tropics, with their occasional hurricanes, and the monsoons of the East, with strong periodic winds and rains. We refer again to the all-important fact of temperate latitudes, the prevailing westerlies, with their cyclones, anticyclones, occasional tornadoes, and frequent summer thunder-storms. We observe again the fact of "continental" or dry interior climates, with wet sea-borders, as shown in nearly all continents, and seen in a conspicuous way if we compare the Great Plains with the Pacific coast, the Central Plateau of Asia with India, or Central Australia with the most of its shore regions. Finally, we observe the effect of altitude on climate when we see the cool summits of the Adirondacks rising from the warmer lands about Lake Ontario, observe the Rocky Mountain snow-fields from the wheat-fields of Alberta, or see the wintry Alps towering above the warm lowlands of Italy.

CHAPTER XII

THE EARTH'S MAGNETISM

The compass. — Consider for a moment how we find our way from place to place. Often we follow a road or path. To cross a field we select some object beyond, and walk towards it. The traveller on a prairie, or in a forest, may notice which way his shadow falls, and guide himself by that. But if clouds hide the sun, that aid fails him, and he takes the *compass*. The compass needle points towards the north; and if he knows which way north lies he can easily lay out a course towards the east or west, or in whatever direction he desires. Such a guide is peculiarly useful on the sea, where neither pathway nor distant object can be seen. Though sun and stars are hidden for many days, the mariner pushes boldly forwards, steering always as the compass directs, and knowing it will not send him astray.

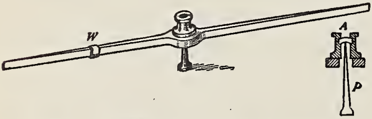


Fig. 139. — A magnetic needle, with a cross-section to show the mode of hanging. *P*, pivot; *A*, cap of agate with hollow beneath to rest on the pivot; *W*, adjustable weight to counteract the dipping tendency.

The compass is a rod or *needle* of magnetized steel, balanced on a pivot so as to be free to swing to the right or left. Like other magnets, it has two *poles*, named north and south. In the instrument made for the mariner several such needles are placed side by side, and all are fastened to the under side of a circular card, which may be either balanced on a pivot or floated on a liquid. On

top of the card is a printed rosette or star with 32 rays, each indicating a direction, or "point of the compass."

Magnetic declination.—While Columbus was sailing westwards in search of the Indies, and before he had found the New World, he made another discovery and one equally unexpected. He found that the needle, instead of pointing steadfastly towards the north star, swung to one side, and the farther he went the greater its error. This was by no means a welcome discovery, for it weakened confidence in a faithful friend, and seemed an evil omen to his superstitious sailors. But it led to a better knowledge of the magnetic needle, and this has been of great value to mankind. The difference between the pointing of the compass and the direction of true north, or the *magnetic declination,* has now been measured at many places and at many times, and maps have been made to show its distribution. In Fig. 141 the lines show by their directions the positions taken by the needle at different places. Thus, at Toronto the compass points west of north. Its direction is still more to the west in Labrador and Greenland. But at Winnipeg, it points a little east of north, while the declination to the east is large in British Columbia. The lines of this system are known as *magnetic meridians.* If we should start with a compass in hand and travel steadily in the direction in which it pointed we should follow a magnetic meridian, and should eventually be brought to a place inside

Fig. 140.—The compass card. Reciting the names of the 32 points is called by sailors "boxing the compass."

the Arctic Circle where all these meridians meet. This place is the *north magnetic pole* of the earth, and is within Canadian Territory, nearly 20° distant from the geographic pole. There is a similar point, the *south magnetic pole,* within the Antarctic Circle. The *line of no declination* cuts the eastern end of Lake Superior. Near Sudbury the declination is 6° to the west; in the Rockies north of Bow Pass it is 25° to the east.

Fig. 141. — Magnetic meridians for North America in 1885.

The declination varies not only from place to place, but from time to time. Fortunately the change with time is slow, so that a good magnetic map is serviceable for many years. The magnetic meridians in Fig. 141, which were made for the year 1885, are not strictly accurate now.

The magnetism of the earth. — Every magnet has an influence on other magnets when they are brought near. It is very instructive to lay a strong magnet on a table and

then move a compass about it. The needle changes its direction with every change of position, now pointing towards the magnet, now from it, and now lying parallel; or, in other words, it is controlled by the magnet. Now, as the compass shows similar changes of direction when it is moved from one position to another about the earth, the conclusion has been reached that the earth also is a magnet. In comparison with its size it is not a strong magnet, but its strength is sufficient for the guidance of those who must journey without beaten paths — the explorer and the navigator.

FIG. 142. — Positions of the dip needle at various points about the globe.

Dip. — The compass needle can swing to the right or left. If it were hung so that it could swing up or down it would usually not lie level, but slant, or *dip*, in one direction or the other. A needle thus hung is called a *dip needle* and is said to show the *magnetic dip*. At the magnetic equator it lies level. Carried northwards, it turns its north end more and more downwards, until at the magnetic pole it points towards the centre of the earth. Carried southwards, its south end is turned downwards, and it becomes vertical with its north end upwards at the south magnetic pole. Fig. 142 shows the dip all about the globe. Close to the magnetic poles the magnetic force is all vertical, and the compass will not act. It is therefore fortunate that these poles are in regions unsuited to man.

There is a kind of iron ore which is magnetic, and fragments of it, called *lodestones*, were the first compasses. Large masses of this ore are contained in the rocks north of Sudbury and about Lake Superior, and they are able to swing the compass and dip needle out of their regular positions. Those instruments have, therefore, been used in searching for this ore, and valuable mines have been located in this way.

CHAPTER XIII

THE OCEAN

We now pass from the lands and the atmosphere to the study of the third great feature of the physical world, the *ocean.* To mankind it is an essential feature, for without it life on the land could not exist. A "good round ball of meadow and ploughland" would be impossible. We must see what the ocean is and what it does.

Ocean-basins. — We give this name to those low parts of the earth's surface which are covered by ocean waters, and we think of the lands as making rims about them. An ocean-basin is vastly broad as compared with its depth, and its bottom is not a plane but a part of the surface of a sphere. Either the top or the bottom of the sea may be thought of as a part of the surface of the round earth. The ocean may be likened to a film of liquid clinging to the outside of a spoon.

We have already seen that all the oceans may be truly regarded as one. In no strict sense can we speak of several basins. The American continents do indeed separate the Atlantic and Pacific, but there is no division between either and the so-called Antarctic Ocean. The same is true of the Indian Ocean and the Antarctic, and in some degree of the Arctic and Atlantic oceans. It is better to think of the waters as forming a spherical sheet over nearly three-fourths of our planet, and broken by a few large and many small bodies of land.

The *sea-floor,* as it is often called, is in general quite smooth, as compared with the land. It has mountains,

but they have still the simplicity of shape with which they were uplifted, and are not cut into a thousand crags and gorges, as on land. It has also many volcanoes, great and small, and these too are unworn. Between and about such mountains and hills is spread an ever-growing sheet of sediment — partly the waste from the land, delivered at the sea-border by streams, partly the myriad shells of small ocean creatures. Of such fine deposits, vast plains are made, smoother than the prairies of Manitoba.

Much of the Atlantic Ocean is 15,000 to 20,000 feet deep. Running in a generally north and south direction through it is a gentle swell of the floor, over which the water is about 12,000 feet deep. The slope from deeper to shallower parts is so gentle that the eye could not detect any variation from a perfectly level plain. The deepest point thus far sounded marks 27,366 feet and lies near Porto Rico.

The average depth of the Pacific Ocean is greater than that of the Atlantic, being $2\frac{3}{4}$ miles. At least two soundings of more than 30,000 feet have been made, one near the Ladrone Islands and the other not far from New Zealand. Thus the greatest known depth of the ocean about equals the greatest known height of land, that of Mount Everest, the measure in each case being nearly six miles. This total unevenness of about 12 miles nearly equals the amount of flattening of the earth at either pole. In this flattening, and in the difference between sea-bottoms and mountains, we have the chief departures of the earth's crust from the form of a sphere.

Continental shelves. — Thus far we have considered only the deeper parts of the ocean-basins. But the deep seas do not commonly come close to the shore-line. For many miles offshore, soundings often show but a few score or a few hundred feet. This is the case along our Atlantic coast. Shallow water surrounds Newfoundland, and a

belt of shallow sea 50 to 100 miles wide runs past Nova Scotia, New England, and down to Florida. A very smooth bottom slants gently down to depths of about 100 fathoms. Then there is a rapid descent to the deep bottom of the Atlantic. The cross profile (Fig. 143) shows these features. This slightly submerged belt is called a

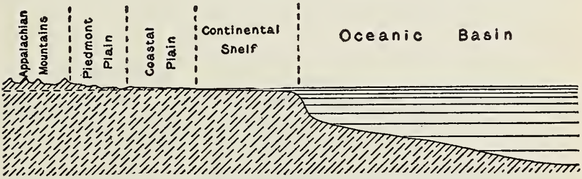


FIG. 143. — Profile of the bottom of the Atlantic Ocean and adjoining land in New Jersey and Pennsylvania, showing the continental shelf. Scale of distances, 1 inch = 140 miles. Scale of heights, 1 inch = 7 miles.

continental shelf, because it seems a true part of the continental block, rising above the deep bottoms. The sea laps over upon the edges of the great land masses.

Our last statement implies that continental shelves are common. The Atlantic shelf may be traced around southern Florida and all about the Gulf of Mexico, except where it is pierced by the Yucatan channel and by the deep passage which carries the Gulf Stream between Florida and Cuba. Another continental shelf is found on the European side. It extends to the westward of the British Islands. Soundings show shallow waters in the North Sea, the English Channel, the Irish Sea, and west of Scotland and Ireland. In other words, these islands rise from a platform which is but slightly overflowed by the ocean waters.

Mediterranean seas. — The water of the Strait of Gibraltar is but 1200 feet deep. But the sea within has depths of 13,000 feet. As it lies between two continents, the name Mediterranean (between lands) has been given

to it. It does not lie in a basin cut out of the land, but in a basin made by the rising of the lands around it. The continents have grown up about a part of the ancient, open sea. On a smaller scale the same is true of the Black Sea, and even of the Caspian, though the latter has no connection with the ocean. The Caribbean Sea and the Gulf of Mexico are also mediterraneans.

Islands in the ocean. — We might call the greater lands islands, because they are washed on every hand by the seas; but we agree to call them continents. The origin of the continents and greater islands is too difficult a subject for elementary study, but the growth of many smaller islands may be better understood.

Fig. 144. — A coral from the Fiji Islands. The flower-like parts are the living animals.

Hundreds of these small lands are due to volcanoes discharging at the bottom of the sea, gradually building their cones of lava and ash to the water-level, and even many thousands of feet above. These form the principal inequalities of the ocean-basins. Detailed soundings over all the seas would show their submerged crests at all depths. In the Atlantic, the Azores, the Canary, and St. Helena are among those that have grown above the sea surface. In the Pacific such shoals and islands are to be numbered by hundreds or thousands. The Hawaiian Islands are among the largest and loftiest.

Around the borders of many of these volcanic islands,

fields of coral flourish in the shallow waters. The coral is an animal of low order, consisting of little more than a sack or hollow body, with a mouth at the top, surrounded by a fringe of simple arms or feelers. It is attached to the mud or rocks of the bottom, and often

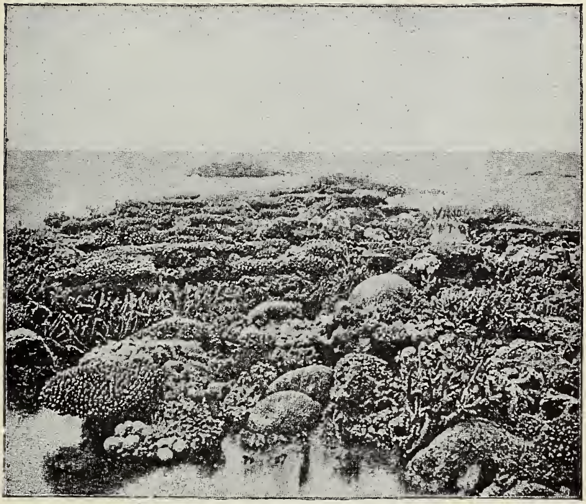


FIG. 145. — A coral reef at low tide; part of the Great Barrier Reef, off the coast of Australia.

great numbers of these simple forms are crowded together on twig-like branches, formed of the calcium carbonate which they take from the sea-water. In colour and form they look like flowers. The waves often break and grind to pieces the skeletons of these lowly forms and make coral-mud. In the shallow seas about the islands, therefore, are fields of living coral and floors of coral fragments and mud. Such a field is a *coral reef*, and when it borders an island it is called a *fringing reef*.

Sometimes a belt of water lies between the high island and a low, long island which is of coral making. On the seaward side of this offshore island the corals are growing. Here we have a *barrier reef,* with a *lagoon* of protected water. In other cases, low coral islands and reefs form a rude circle or loop, with a shallow basin of quiet water within. Corals, as before, thrive all about the outside in the shallow water, while the coral sand, heaped by waves and winds, forms the low islands, clad with palms and other tropical plants. Such a bracelet of low islands is an *atoll.*

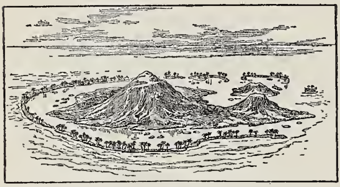


FIG. 146.—A volcanic island encircled by a barrier reef and lagoon.

The student should remember two or three important facts about corals. They are not "insects," but are far below these creatures in their rank as animals. They have no instinct which prompts them to build islands. They do not work from the bottom of the sea. Most of them cannot live below a few hundred feet of depth. That they "build" anything is wholly due to the crushing and pushing of their remains by waves and winds. And finally, they can live only in water having temperatures of 68° or more. Hence they are never found far from the tropics. The Bermudas are the most northerly of coral islands. The Galapagos

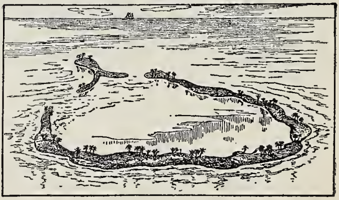


FIG. 147.—An atoll.

Islands, close to the equator in the Pacific Ocean, have no bordering reefs, because ocean currents bring cold water from the southern seas.

The saltness of the ocean. — The rivers which flow into the ocean have dissolved various salts from the soils and rocks over which their waters have come; and these are left behind when the water of the sea is evaporated, so that they accumulate from age to age and make the ocean salt. Whoever has bathed on the seashore must have noticed that there is a bitterness as well as the taste of common salt in its water. In fact, there are many other salts besides common salt in the ocean. If 100 lbs. of sea water were evaporated, there would be left 3·4 lb. of these mixed salts, three-quarters being common salt and the rest salts of magnesia, potash, lime, etc. The saltness of the sea varies little from point to point, though it is somewhat diluted where rivers come into shallow gulfs, as in the Baltic, and somewhat more concentrated where there is great evaporation, as in the Red Sea.

It is surprising to find very little calcium carbonate in the ocean, though this is the commonest substance dissolved in spring or river water. Marine animals constantly remove it to build up their shells, which are slowly turned to limestone on the sea-bottom as generation after generation of these animals die.

Temperature of the ocean. — The surface waters are warm in the tropics, cooler in temperate latitudes, and cold in the polar regions. Near the equator about 80° is the prevailing temperature. Some closed seas like the Red and the Persian Gulf attain almost to blood-heat. In the polar regions the temperatures go down to the freezing point of 28° or 29°, varying with the amount of salt in the water. Warm waters push into northern and southern seas by means of ocean currents, and cold waters

invade temperate latitudes in the same manner. Such cold drifts come from Greenland into the Atlantic, often floating chilling fleets of icebergs.

We have spoken only of surface temperatures: we are now ready for the important statement that no such wide differences are found in the temperature of the deep waters in different latitudes. The sun's rays affect only the surface waters. Even in the torrid zone the bottom waters are always cold, having temperatures of 35° to 40°. There is a considerable drift of surface waters from low to high latitudes. On the contrary, the water from north and south slowly creeps towards the equator in the depths. This accounts for the coldness of the deep waters everywhere.

Movements of the ocean waters. — Even in the deepest calm the ocean is never perfectly still. It is more fixed than the changeful sea of air above it, and less stable than the lands that border it. But even the lands are never twice quite the same, and so, from beginning to end, geography deals with an unfolding world. The movements of the sea fall into three classes, waves, tides, and currents.

Waves. — The winds ruffle the surface and make a series of ridges and furrows. The summit line of a single wave is its *crest* and the furrow is the *trough.* Under a moderate wind the crest will be a few feet higher than the trough. In storms the waves may be 20 or 30 feet high. In powerful storms the height may rise to 40 or 50 feet. Even great ships must be guided across the crests of such waves, or be overturned by the rolling motion. Wave motion ceases a few hundred feet below the surface, for the winds cannot affect the deeper waters.

It will be remembered that even a small steamer may raise waves astern, and that a gentle swell may afterwards be felt at some distance, if we cross the track of the

steamer in a small boat. On a larger scale the wave motion in a region of ocean storm is passed on, and may create a swell in quiet seas, thousands of miles away.

Waves may be studied conveniently on a pond which is stirred by the wind. Drop a twig in the water, and observe its motions. It may drift slowly, but does not travel so fast as the waves. As each wave passes, it rises and falls; on the crest it moves a little forwards, in the trough a little back. The motion of the twig is also the motion of the particles of water about it, and it shows their motion to the eye. The wave is not a body of water gliding forwards, like a current, but a travelling shape of water. A field of grain swaying in the summer wind shows how the sea may keep its place while the wave moves on.

While urged by the wind, the larger waves sometimes break and whiten at the crest, even in the open

FIG. 148. — Breakers where waves approach a sheltering shore.

sea, and nearly all waves break at the shore. As a wave moves through shallow water near the shore, the crest goes faster than the base, the front becomes steeper, and finally the crest falls forwards in a cascade.

This tumbling crest is a *breaker*. As the advancing cascade looks like a turning cylinder, the term *rollers* is sometimes used. If the bottom descends slowly, a series of waves may be seen thus breaking, the water of the in-shore breakers rushing up the slopes of the strand. This water pours back by a swift flow along the bottom, under the onrushing surface waters, and is known as the *undertow*, so dangerous to bathers in the surf. The changes which waves cause along the shore will be described in the next chapter.

If a strong earthquake happens under the sea, a shock may be communicated to the waters, and great waves may be raised. The term *tidal* should not be applied to these waves. In some parts of the world, as Japan and Chile, and the Straits of Messina, such waves have rushed in over the coastal lands, overwhelmed cities, and stranded men-of-war and other vessels at some distance inland. Such a wave travels swiftly across the seas as a broad swell, and breaks with destructive force at the shore. The Lisbon shock in 1755 sent forth a wave that deranged shipping and flooded streets of an Irish port, while the shaking that accompanied the eruption of Krakatoa in 1883 caused half the waters of the earth to vibrate with wave motion. On neighbouring shores these waves rolled to heights of 60 or 70 feet.

Tides. — If we stand on the shore of the open sea, we shall observe a regular rise and fall of the waters, even in a time of calm. If the surface be at its highest level now, about six hours later it will be at its lowest. In case the shore is rocky, the boulders and cliffs up to a certain height will then be seen covered with barnacles and dripping seaweeds. Pools left by the receding waters will be full of small, shelled creatures, and a strand several rods, or even miles, in width may be left bare. In another six hours the waters will have crept slowly in again until the

upper line of seaweeds is reached. The average interval between two periods of *high tide* is twelve hours and twenty-five minutes. The alternating extremes mark *low tide*.

About the shores of islands the rise and fall are small, often not more than 2 or 3 feet. On the borders of continents the change is greater. Towards the head of a long bay which has an open mouth and narrows gradually the rise and fall may be 50 feet, or even more. The Bay of Fundy and the estuary of the Severn fulfil these conditions, and are noted for their great tides. On open shores the water falls back, or creeps up, gently. But in and out of these landlocked arms it goes with a rush. An abrupt tidal wave with a steep and foaming front enters some rivers, as the Seine. Such a wave is called a *bore*. High and low tides do not always occur at the same time on opposite sides of a strait, and the difference in level causes a swift current, known as a *tidal race*. Seymour Narrows, between Vancouver Island and the mainland, affords an illustration. In a landlocked sea which has a very narrow entrance from the ocean, the tides are unimportant. Those of the eastern shores of the Mediterranean Sea are scarcely perceptible.

FIG. 149. — The Bore on the Bay of Fundy.

The tides exist, but cannot be seen, in the open ocean. They are broad, gentle swells, which, like wind waves, pile up and become visible at the shore. If the earth were covered by a universal ocean, the tidal waves would

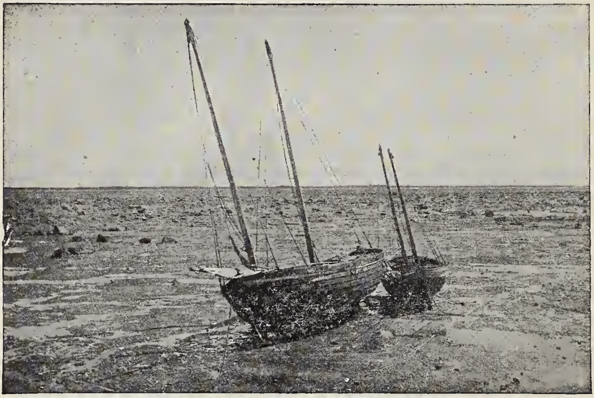


FIG. 150. — Low tide on a shelving coast. The edge of the water is now far away and the boats are stranded. When high tide returns they will again float.

forever roll around it unseen. But the lands bring them to view.

What is the cause of the tides? — What can make a wave come to its height every twelve hours and twenty-five minutes? Twice this period, or twenty-four hours and fifty minutes, is the time from one setting of the moon to the next, and this fact long ago led people to connect the tides with the moon. But many centuries passed before the relation was wholly understood. The full explanation would take so much space that we must content ourselves with a simpler statement. Suppose a man and a boy to join hands and whirl about. Each

will move in a circle, but the boy's circle will be larger than the man's because he is not so heavy. Each will feel a pull in his arms, and they must hold fast or they will break apart. The moon and earth whirl about in a similar way, making one turn a month, but as the earth is eighty times the heavier, the centre about which they circle is close to the centre of the earth. It is in fact inside the circumference of the earth. Instead of clasping hands they are held together by *gravitation,* the same attractive force which keeps us from being whirled off by the daily rotation of the earth. The earth attracts the moon and the moon attracts the earth. Thus the earth feels two forces — an attraction or pulling towards the moon, and a pulling away from the moon in consequence of the circling. The pulling away is called the *centrifugal force.*

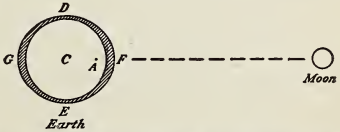


FIG. 151. — Diagram to illustrate the tides. The shaded belt represents the ocean, as though a complete envelope.

To make this quite clear let us look at Fig. 151. *C* is the centre of the earth, and the circle about it is the equator. *A* is the point about which the moon and earth circle. The centrifugal force is the same for all parts of the earth, but the attractive force is not. The principle is that attraction is stronger for small distances than for large, and under this principle the moon draws the nearer side of the earth more than it does the farther side. At *D* and *E* the moon's attraction is just as strong as the centrifugal force, but nowhere else about the equator. At *F* the attractive force is greater than the centrifugal, and the difference is a pull towards the moon. At *G* the centrifugal force is greater than the attractive, and the difference pulls away from the moon. So there

is a tendency to stretch the earth out, making the diameter *GF* greater than *DE*. The water of the ocean yields to these pulls and is drawn together and piled up a little about *F* and *G*. These two swellings of the water (greatly exaggerated in the diagram) are tidal waves.

Up to this point we have paid no attention to the fact that the earth turns once in twenty-four hours about its own center, *C*. The effect of this turning is to carry the tidal waves all about the earth's circumference each day, and as there are two of the waves, each part of the ocean feels two high tides and two low tides. Thus the tides are caused by a combination of the moon's attraction with the motions of the earth.

The continents and islands and the shapes of coasts and shoals interfere with the free movements of the waters, but in each ocean the water is swayed twice a day, and from the oceans tidal waves advance against the coasts, and enter all the bays. Their speed is checked as they enter shallow water, and their arrival at the heads of long bays may even be delayed many hours. For the guidance of shipmasters, maps are made showing, by *cotidal* lines, the places which are reached by the tides at the same time. There are also *tide-tables* for all ports, to tell the mariner when high and low tide occur, and the amount of rise and fall. Many channels may be used at high tide, which cannot be passed at any other time, hence the knowledge of them is of much practical importance.

Spring tides and neap tides. — If one watches the tides from day to day, one soon finds that not all high tides are equally high and not all low tides are equally low. For a time there is gradual increase in the amount of rise and fall of the water, and afterwards gradual decrease. The series or cycle of changes is completed in half a month, or, more exactly, $14\frac{3}{4}$ days. The day on which the water

rises highest is also the day on which it falls lowest, and these extremely high and low stages are called *spring tides*. A week later come the *neap tides*, when the high-water stage is least high and the low-water stage least low.

The explanation of spring tides and neap tides is connected with the sun. The sun's attraction, like the moon's, tends to produce a pair of tidal waves, its tidal force being about half as strong as the moon's. At new moon (*A*, Fig. 152), when the sun and moon are in the same direction from the earth, their tidal forces work

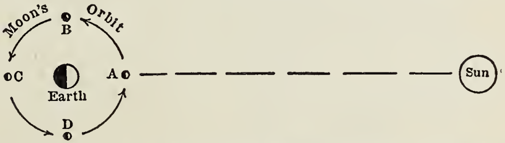


FIG. 152. — Diagram to show the changing relation of the moon to the earth and sun. When the moon is at *C*, we see the illuminated side and call it "full"; at *B* and *D* we see only half of the bright side; at *A* the dark side is towards us.

together, making spring tides. A week later, when the moon has moved to *B*, it tends to make high tides on the sides of the earth towards *B* and *D*, and low tides towards *A* and *C*; but the sun at the same time tends to make high tides towards *A* and *C*, and low tides towards *B* and *D*. As the moon's influence is the stronger, the effect of the sun's influence is only to lessen the moon's tidal effect, and neap tides are the result. When the moon reaches *C* the tidal forces again work together, making spring tides; and with the moon at *D*, they are again opposed, making neap tides.

Ocean currents. — When waves started by winds, earthquakes, or tidal attraction traverse the ocean, the water itself moves little except in shallow or confined areas. We are now to study movements of the sea in

which there is a continual transfer of water for long distances.

We take first the *Gulf Stream* and the *North Atlantic Drift* (Fig. 153). The term Gulf Stream is properly applied to a stream of salt water which pours eastwards from the Gulf of Mexico, between Florida and Cuba, and then bears northeastwards into the Atlantic. The width of this current in the Florida Straits is about 50 miles, its velocity is about 50 miles a day, and it is several hundred feet deep. It is very warm and it passes between "walls" of colder water. As the stream progresses, its waters scatter, their velocity drops to a few miles a day, and thus as a *drift* they cross the middle Atlantic and wash the shores of western Europe. It is hardly correct to say, therefore, that the Gulf Stream touches Europe or

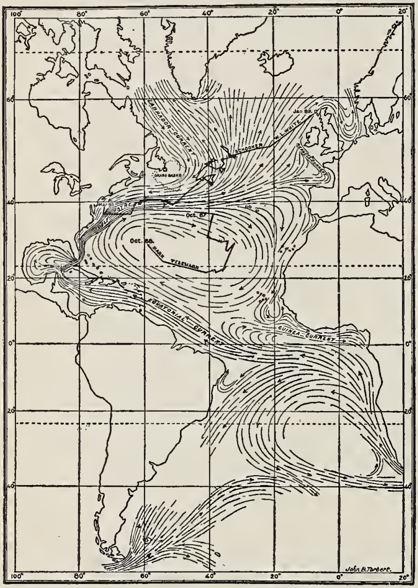


Fig. 153.—Currents of the Atlantic Ocean. The arrow shows direction. The heavy lines are the courses of two derelicts, drifted by currents and winds.

gives it a mild climate. It is true, however, that the neighbouring waters are warmed by the drift from the tropics, and the mild winds carry heat and moisture from the sea over the lands of western Europe.

But the currents of the North Atlantic have now been described only in part. Flowing westwards along the equator is a strong current, some of which passes South America, enters the Caribbean Sea, and then the Gulf of Mexico, to pass out as the Gulf Stream. Other strands of the equatorial current turn north outside of the West Indies and join the Gulf Stream waters to form the drift described in the foregoing. At the far north-east some of the waters push on into the arctic seas, and others return southwards along the shores of south-western Europe and western Africa, and pass again into the equatorial current moving west. There is thus a complete eddy in the North Atlantic, the waters moving as the hands of a watch. In the centre is a quiet region, where vast fields of seaweed float, known as the *Sargasso Sea.*

Beyond Florida the Gulf Stream soon bears away from the shores of the United States, which are washed by colder waters from the north. These come down from the neighbourhood of Greenland and meet the Gulf Stream in what is known as the *cold wall.* Along this belt are the Banks of Newfoundland, and here the contact of cooler with warm, moist air causes dangerous fogs.

There is a similar eddy in the South Atlantic. A division of the equatorial current turns south-westwards down the coast of South America, and returns eastwards to Africa, and northwards, completing the circuit. At the south the easterly flowing current mingles with a great drift passing easterly around the world in the southern seas. This South Atlantic eddy whirls in a direction opposite to that of the hands of a watch.

It may now be asked: How are these currents known to exist? The answer is, by the course taken by drifting objects. Certain floating but abandoned ships, known as *derelicts,* are now and then sighted by vessels, and by comparing successive positions, their course may be plotted. Experiments are also made from time to time with sealed bottles cast into the sea. Less than in former days is the sea a trackless waste.

In the Pacific the swing is more vast, but the general arrangement of eddies is similar to that of the Atlantic, and the *Japan Current* resembles the Gulf Stream. The northern eddies of both oceans are more perfect, because formed in more fully inclosed waters.

FIG. 154.—Floe ice, near the west coast of Greenland. Great cakes, crushing together, are made hummocky at their edges.

The currents are formed by the winds. This is seen on a small scale by watching the floating twig in the pond, and is understood for the oceans by studying the winds and currents together. The student should compare the winds of the Atlantic (Fig. 134) with the currents of the Atlantic (Fig. 153). The great current-makers are the steady trade-winds, driving the waters westwards in the tropics; the prevailing westerlies of middle latitudes drift them eastwards, and thus the great eddies are maintained.

Ice in the sea. — Icebergs, singly or in fleets, leave the shores of Greenland in the spring and descend far enough into the Atlantic to endanger ships in the great path between America and Europe. The icebergs are the frontal parts of Greenland glaciers which have pushed into the sea far enough to float. All northern seas are more or less crowded with pack or floe ice, formed by the freezing of the surface waters, and moved about by winds and currents. Polar exploration abounds in experiences with such ice. Ships are caught and crushed in it. Long sledge-journeys are made over it. Through it Nansen drove the *Fram*, and over it Peary made his journey to the pole. Large, flat-topped icebergs break from the antarctic ice-fields and invade the South Atlantic and South Pacific oceans.

Exploration of the ocean. — This has been done in many ways. In ancient times, daring mariners in small ships learned to track the wastes of the Mediterranean. Then they sailed through the straits of Gibraltar, and began to creep up and down the Atlantic shores. Hardy vikings of the north found Iceland, settled in Greenland, and, as many believe, followed our shores as far as the New England States. Then came Columbus, Magellan, Drake, Hawkins, and Cook, crossing the great oceans and beginning to sail around the world. In our modern days commerce has threaded all waters, daring explorers have pushed far into the frozen north, and ships have gone forth, equipped with apparatus and directed by men of science, to seek the mysteries of the ocean. The forms of the shores, the currents, the temperature, composition, and depth of the water, the life of the upper and deep waters — all these are subjects of study. Sounding-lines, dredges for bringing muds from the bottom, and self-registering thermometers for testing temperatures at the bottom, are parts of the apparatus used. Expeditions like that of

the *Challenger* have furnished us with much of our knowledge of the oceans.

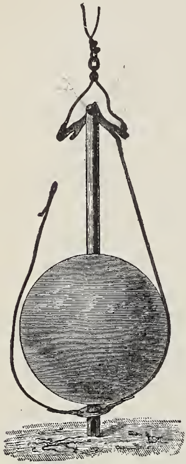


FIG. 155. — To carry the sounding wire to great depths a heavy weight is needed. It cannot be drawn up again, and is therefore so arranged as to disconnect itself at the bottom.

FIG. 156. — A deep-sea dredge. The iron lip of the sack scrapes shells, mud, etc., into it, and small animals are caught by the "tangles."

Life of the ocean. — The highest forms of life are on the land. There they find abundant supplies of air, and are able to live an active life. Even the beasts have more elaborate bodies and far more intelligence than the highest creatures that live in the sea. But all land creatures are close to the surface, while the ocean is rich in living creatures, not only near the shore and at the surface in mid-ocean, but at the greatest depths. Vast numbers of sea animals have delicate, jelly-like bodies, made almost entirely of water, and able to exist only in water. Others, equally confined to a watery home, have

hard skeletons, either internal, like the fishes, or on the outside, like the crab, the lobster, and the innumerable creatures which form shells as a cover for their bodies. More will be said of sea animals in the chapter on life.

Deposits in the ocean. — We have seen that rivers may enter the sea and build out the land, as their deltas grow. But not all the waste of the continents is dropped at the water's edge. The finer mud floats for a long time, and finally settles to the bottom far from the river mouth. Thus the continental shelves, and even deeper waters outside, receive a cover of muds derived from the land. The shallow waters teem with fishes and shell creatures, and at death their remains mingle with the muds. Far out, however, the fine muds from the land do not go. But multitudes of minute shells are formed by creatures in the surface waters.

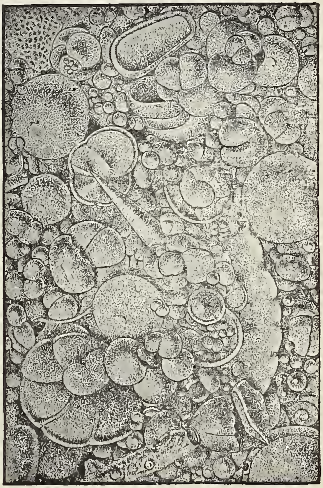


FIG. 157. — A deep-sea deposit composed of shells. Magnified 20 times.

These shells, chiefly made of calcium carbonate, sink, when the animals die, to the deep sea-bottoms. They make a fine chalky ooze (Fig. 157), which has been brought up by the dredge and studied. In the very deepest seas a fine red clay is found. This comes, in part at least, from volcanic dust, which falls on all seas.

The fine deposits of mid-ocean accumulate very slowly, while the muds of offshore waters gather rapidly.

Navigation. — The ocean is the highway of nations. In primitive times the winds furnished power and the sun and stars guided the course. Now the mariner has a charted sea; with his compass on the deck and engines in the hold, he crosses the waters whither he will, and his speed is scarcely checked even by waves and winds. Storms bring little danger to the great steamship, and collision and fire are so well avoided that travel is nearly as safe on the ocean as on the land. Even the waves are robbed of their fierceness by allowing a little oil to drip from the prow, and a ship with its hundreds or thousands of temporary inhabitants, and with all provision for human comfort, seems less a vehicle than a floating town. The Pacific is coming to be a busy highway like the Atlantic, and the building of the Panama Canal in Central America will make possible in the tropical regions continuous voyaging around the world. Almost equally with the land, is the sea a field of discovery, of travel, of commerce, and, unhappily, also of war.

Submarine cables. — During the last half of the nineteenth century many lines of telegraphic communication have been stretched across both the Atlantic and the Pacific Oceans, and important foreign news passing between civilized lands is now rarely one day old.

Fishing. — The seas are an important source of supply for man. The shallow waters near the shore teem with fish and other marine animals fit for food. Hence fishing communities abound on the shore. From the beginnings of voyaging to America, fishing has been carried on over the Banks of Newfoundland, and Great Britain, France, and the United States have regarded these ocean fields as of national importance.

CHAPTER XIV

THE MEETING OF THE LAND AND THE SEA

THE line along which the ocean waters wash the edge of the land is often called the *shore*, or *shore-line;* or we may use the term *coast*, or *coast-line.* The latter suggests more particularly the margin of the land, the former the border of the sea. We have deferred our study of this narrow belt, that the chapters on the ocean and the land might prepare us to understand it. We have already learned some facts about sea-borders, as in

FIG. 158. — The shore-line of Nova Scotia.

connection with deltas, coastal plains, and tidal bays. We shall now look at the shore-lines of Canada to see what general principles we may gather from them.

Shore-line of Nova Scotia. — This will be understood by reference to the map (Fig. 158). Many rocky ridges

run in a southerly direction from the mainland into the sea. Between them, deep bays penetrate the land. The headlands are exposed to the full force of the waves, hence no sands or gravels can lodge, or beaches form about them. At the head of the inlets, however, the sands and clays, whether brought down by streams or swept in by waves, may lodge and form floors of worn waste, to which the name *beach* is given. The south parts of these ridges are often surrounded by water, forming hundreds of islands fringing the shore. The shore-line is vastly lengthened by its irregularity. The rivers enter the sea through deep tidal channels. These furrows, cut in the edge of the land and entered by the sea, are known as *fiords*, and have their best examples along the shores of Norway and British Columbia. They were begun by rivers and finished by glaciers during the glacial period.

All the southern and eastern coasts of Nova Scotia have this jagged, rocky character; and this is even more striking in Newfoundland and along the Labrador coast, where hard rocks carved by ice meet the storms of the north Atlantic.

Shore-line of the Gulf of St. Lawrence. — About the Gulf of St. Lawrence there are, in many places, shores of a different kind. Near Miramichi Bay the beds of rock are softer and more easily destroyed. They have been carved away by the unceasing attacks of the waves. Much of the material has been swept across the mouth of the bay and built into sandbars. Here the shores have smoothly curved forms. Within the narrower part of the St. Lawrence, along Gaspé and the north shore, the coast-line is often of hard rocks and of a very rugged kind, though sand and gravel bars sometimes partly inclose the bays. The Saguenay River is a fine example of a fiord, with towering walls on each side, and deep water between.

British Columbia. — The shore-line of British Columbia, unlike that of Oregon and California, is very intricate, a tangle of islands, fiords, and inlets with mountainous

FIG. 159. — The shore-line of British Columbia.

shores. Measured by the shortest line from the State of Washington to Alaska the coast is about 600 miles long. Measured along the windings of the fiords, without considering minor inlets or the shores of islands, it is more

than 2300 miles long. If we include channels between islands as well as fiords there are more than 2500 miles of narrow waterways perfectly protected from ocean storms, and usually deep enough for the largest vessels. The number of possible harbours is endless. Northwards along the Alaskan coast the complexity is even more striking, while southwards from the State of Washington to Mexico there are hardly a half-dozen indentations sufficient to make a harbour.

Summary of principles. — Having learned the chief facts about our coast-line, we shall now classify and more fully explain them, and compare with them some of the features of other parts of the world. The behaviour of the water where it washes the land is much the same everywhere, giving us the same kinds of coast forms. Even on the borders of pools and small lakes may be found in miniature what the ocean displays on a scale of magnificence.

Wave work. — We have already learned that winds raise waves, that waves move over the sea, that they break against the edge of the land, and send the water rushing upon it. These waves attack the rocks of an uneven land border. They pick up pebbles and stones and hurl them against the ledges of the shore. Grinding away the lower ledges, they undermine the ledges higher up, and thus form cliffs. In front of the cliffs nearly flat platforms are made, and strewn with the coarser waste. The finer mud, easily washed away, is floated out, to settle at a greater or less distance from the land. Waves do the most of their work at the level of the sea. Storm-waves may dash a hundred feet or more above it, and may grind strongly over shallow bottoms, but they have no effect on the deeper bottoms. The waves act as a saw, cutting horizontally against the edge of the lands.

Beach platforms. — Let us look more closely at the stretch of sand, pebbles, or boulders that so often borders

the sea. The wave-saw has cut a notch into the sloping land, and the continual moving in and out of waves and tides strews the floor with the waste of the land. This platform slopes gently towards and under the water. It may be covered entirely at high tide, but a strip, perhaps many rods wide, is bare at low tide. Sometimes the beach platform is a floor of solid rock. This means that waves, or currents moving along the shore, sweep all the waste to some other point.

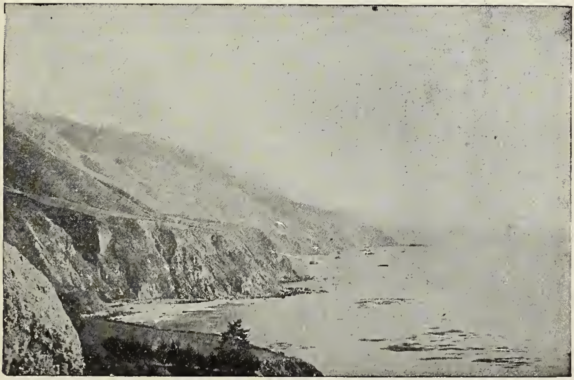


FIG. 160. — Cliff on the coast of California wrought by the waves of the ocean.

Sea-cliffs. — Overlooking the beach, if the sea beats upon the edge of high land, is a cliff. It may be vertical and rise for hundreds of feet, as at some points on the shores of Scotland and British Columbia. It may even overhang in places, if the rock is strong enough to hold, and sea caverns may have been formed underneath by the dash of the surf. Fingal's Cave is cut 200 feet into the south side of the island of Staffa, off the Scottish coast. The floor of the cave is below the sea surface, and the roof is 50 or more feet above it. The waves rush in and are still quarrying out

the great columns of ancient lava that compose the island.

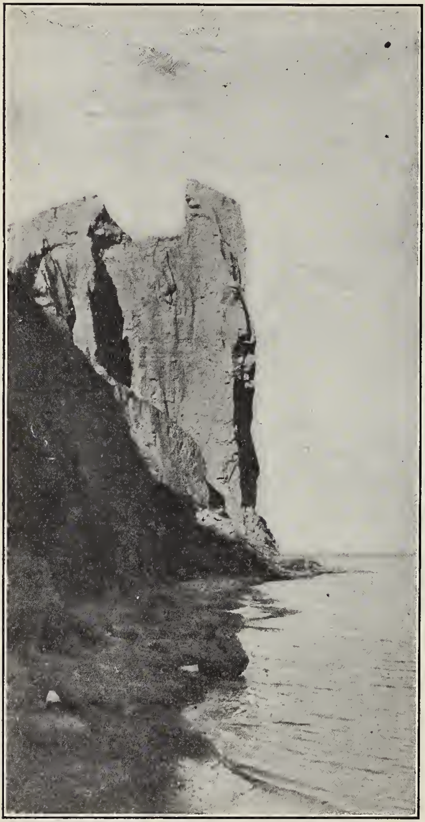


FIG. 161.—The "Dutch Church" at Scarboro, near Toronto.

Where the border-land is not solid rock, but clay or sand, the cliff slopes down to the beach more gently, as seen at Scarboro Heights on the shore of Lake Ontario. At the "Dutch Church," however, the clay is firm enough to stand up as a steep cliff. There are many such cliffs in the soft beds of Norfolk and other parts of the east English shore, where farms and village sites have in times past been cut away and absorbed by the North Sea.

Lagoons and barrier beaches. — These belong to shore-lines along which the water is shallow for some distance

from shore. This means that incoming storm-waves break at some distance from the land, and spend their force there. The rush of the surf stirs the waste on the bottom, carries it forwards a little way, and then drops it. By this process a low ridge is raised from the bottom, is built at length above the water, and may be broadened by the addition of waste against its outer slope. The quiet water on the land side is known as a *lagoon.* It receives fresh water from the land, and tends to become brackish. Muds from the land gather in lagoons, and plants grow in them, and they are gradually filled.

Fig. 162. — Barrier and lagoon on the shore of Lake Ontario.

Travelling beaches and spits. — Often the same wind which makes large waves will cause a current to flow along the shore. The waste lifted by each wave is then carried forwards a little by the current before it drops again to the bottom. In this way the waste slowly travels in the direction of the current. If the shore is straight the waste follows it, but if the shore-line bends back the waste keeps straight on, and is built into a low cape or *spit.* Toronto Island is a spit curved at the end (Fig. 163). Sometimes the spit grows all the way across a bay so as to close it, and sometimes it joins an island to the mainland. A barrier usually becomes a travelling beach also, and its sand is shifted to and fro as the shore current changes.

Irregular shore-lines tend to become smooth. — Let us take the New Brunswick shore as an illustration. Wherever a stream enters the head of a bay it makes a delta and shallows the water, or even pushes the shore-line forwards. At the same time the waves cut away the exposed headlands, and while some of the waste from this cutting goes

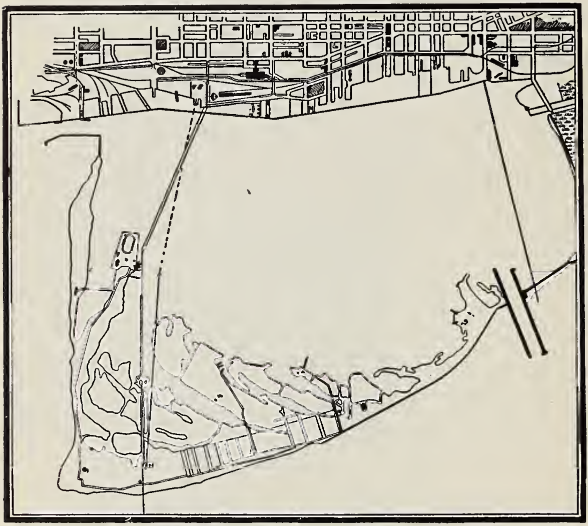


FIG. 163. — Map of Toronto Island.

out to sea, some of the sands and gravels are often swept into the bay, and form within it a curved, smooth beach. This curve may straighten out as it receives more material, and so by this double or triple process the entire shore-line will grow in time to be smooth and uniform. Where the headlands are of soft materials, the work goes on rapidly, the spits soon become barriers, and the bays are shut off from the sea and become lakes.

FIG. 164. — A travelling beach on the shore of Lake Ontario. The stones, originally angular, become rounded as the waves roll them along.

Coast-lines of rising lands. — Consider a land standing at a given height in relation to the bordering sea. The waste of the land is spread smoothly in the shallow waters. If the land rises, these plains of waste become flat grounds on the edge of a continent. We have followed such changes in our study of marine plains. Such a coast-line is smooth, and the waters deepen very gradually from their edge. Hence offshore beaches will form. These are the conditions of the south Atlantic coast of the United States.

FIG. 165. — Beach at the head of Conception Bay, Newfoundland. The waves have here made the shore-line smooth.

If coasts are steep and the seas deepen rapidly, no

marine plain is uncovered by the rising of the land, but a beach platform and cliff is carried above the sea surface and left as an ancient sea margin on the slopes that rise from the water. Such old beaches, or marine terraces, are found along the Gulf of St. Lawrence, and along the ocean borders of the northern United States, Labrador, British Columbia, Alaska, Cuba, Norway, and Scotland.

Lake shores. — In lakes the tides are unimportant. Wind waves do their work on ocean and lake border alike, except that most lakes are so small that the waves have little space in which to develop, and are therefore small and weak. Still, upon lakes less than a half-mile wide, well-developed beaches are often found, and a succession of little horizontal platforms or beaches may often be found running about a pond or reservoir whose waters have been drawn down. At each stand of the surface, a new shore-line is made. Even where a pool has dried away by the roadside, beaches, deltas, bars, and spits may often be seen.

FIG. 166. — The meeting of water and land, Lake Superior.

Harbours and cities. — The waters of the St. Lawrence near Quebec are protected from the ocean waves by surrounding lands. They are not so broad that the winds can stir up great waves upon them. They are deep enough for sea-going vessels, and are connected by a deep channel

with the ocean. Hence they form a harbour. Halifax Harbour is in a recess of the shore-line protected by an island, and St. John, New Brunswick, is at the land-locked mouth of a river. Vancouver Harbour is on Burrard Inlet, a well-protected arm of the Straits of Georgia. Esquimault Harbour, near Victoria, is a well-sheltered inlet from the Straits of Juan de Fuca.

The great seaports of the United States, such as New York and Boston, on the Atlantic, and San Francisco and Seattle, on the Pacific, are of a similar kind to the Canadian ports described.

Fig. 167. — Outline of England, showing the relation of its great commercial cities to drowned rivers and the drowned valley north of the Isle of Wight. Scale, 1 inch = 250 miles.

In general, sinking or sunken coasts have many harbours, and rising coasts have few. The point where ships may come safely to the land is the natural home of commerce. There men gather, there manufactured products are made, and may at will be sent seawards or landwards. The relation of a harbour to the land is also important. The supremacy of Montreal is due to its position at the head of ocean navigation, and the beginning of a great chain of inland waterways and of railways in the flat St. Lawrence valley.

Great Britain's commercial greatness has grown in part from her drowned rivers and resulting harbours. She

has no river that would be important if not tidal. London, Bristol, Liverpool, Southampton, and Glasgow are great cities because of the sinking of the land. But not all harbours are in fiords and drowned valleys. In the lower or delta channels of great rivers, as at New Orleans, or New Westminster, shipping may find a haven.

CHAPTER XV

LIFE

We have looked upon the Earth as a whole. We have studied its lands, its atmosphere, and its mantle of waters. We come now to the living things which throng our planet. They are animals and plants. The botanist studies the plants, tells us their structure, their habits, how they are related to one another, and how they divide into small and great groups. Zoology is devoted to the animal kingdom, and gives to those who seek it the same full knowledge of these forms. But geography seeks only to know the greater truths about living things. Plants make a carpet over the lands — a carpet varying according to climate and soil. Animals, too, are found in groups over the world, devouring plants and other animals for food. Living things, covering the land and swarming in the seas, and seen in their grouping and general relations, belong to geography.

Plants of North America

Forests. — The great hardwood forests of North America are in its eastern half, in the regions of the Appalachians, and the Great Lakes. Chestnut, oak, maple, beech, walnut, and cherry are among the hardwoods of the East. The broad-leaved trees chiefly compose these forests, often numbering 50 kinds or more, while the narrow-leaved or coniferous trees show a half-dozen sorts. White pine, hemlock, and spruce are common in the Maritime Provinces, Quebec, Ontario and the New England States. In the southern United States hard pines flourish, with

magnolia, tulip, gum, and cypress. The Great Plains and the prairies have few trees except along the rivers.

Only two parts of Canada are treeless. One of these is the great, triangular prairie region, stretching north towards Edmonton. The other is the far northern area, called "barren grounds," which is too cold for forest growth. Much land in the south-eastern provinces has been cleared, but enormous forests stretch from the Laurentian uplands to Hudson Bay, the basin of the Mackenzie River, and southwards along the slopes and valleys of the western mountains. The latter extend over Alaska to the Pacific coast. At the east are pine, white and black spruce, larch, aspen, and birch. At the west are spruces, firs, hemlocks, and cedars. The softer woods, like spruce, poplar, and basswood, are much used for making wood pulp.

Fig. 168.—The Cathedral, Stanley Park, Vancouver, B.C.

Southern Mexico and Central America show forests of the tropical sort. Palms, rosewood, mahogany, logwood, and rubber trees are common, while upon the mountains more northern types, such as oaks and pines, are found.

Forestry. — This is the name given to a scientific system of managing woodlands. In the early days the settlers cut off the forests wastefully, to clear the land. Now it has become a matter of public interest to regulate tree-

cutting and to plant forests. This is important, in part to keep a supply of timber, and in part to regulate floods and prevent the wasteful washing of the soil. The cutting of the woods exposes the spongy cover of mosses and leaves to destruction, and lets the storm and snow-water run swiftly off as floods, while at other times the water is low and scanty. In other words, the soil mantle and its nap of vegetation serve as a reservoir to hold the water and dole it out throughout the year. In Ontario there are several large forest reservations in parts not suited for the farmer. Their care consists mainly in cutting only the mature timber, instead of reaping a wasteful harvest at the expense of the future. Equally important is the protection of forests from fire. More than half of the timber wealth of Ontario has been burnt. The government now stations fire rangers in the timber limits to guard against this danger.

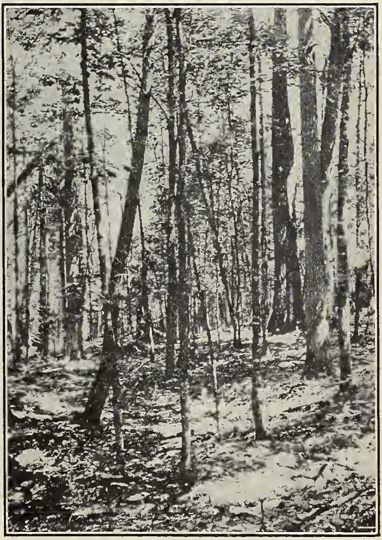


Fig. 169. — Hardwood forest, near Lake Erie.

Small plants in forests. — In the moist and shaded places beneath forest trees low growths flourish. If enough light streams in, flowering herbs will thrive, as in

our northern woods, and in any case mosses and other lowly plants will establish themselves. Hence we may think of these wild grounds as having several layers of vegetation, from the modest mosses up to the forest monarchs.

Natural meadows. — This is another name for *prairies.* Trees are absent except along the streams. Coarse grasses and large flowering herbs cover the ground in its natural state. The glowing colours of the aster, goldenrod, and

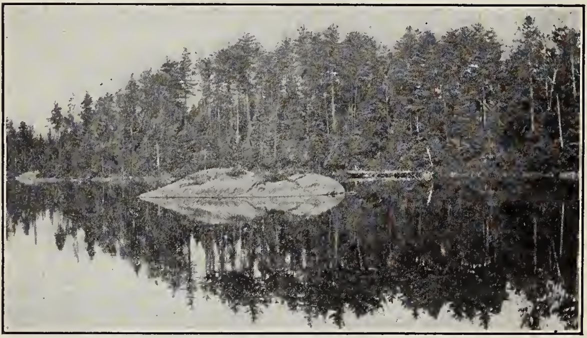


FIG. 170. — A pine forest in northern Ontario.

other tall plants are common. The great prairie region separates the region of the eastern forest from the western. But the climate of the prairies is not unfavourable to tree growth. The tree limit has been crowded eastwards beyond its natural position by fires. Much attention is now being given to tree-planting in Manitoba, Saskatchewan, and Alberta, and with excellent results.

Alpine plants. — The term *alpine* is derived from the lofty mountains of southern Europe, but applied to similar characters and conditions wherever found — to scenery, climate, plants, animals, and even the customs of men. In eastern North America most of the mountains are too

low to reproduce alpine conditions of plant life, and forests usually rise to the top. But in the western mountains are high fields and slopes, above the timber-line, where the ground is often closely covered by a mat of low plants, with flowers of many and brilliant hues, resembling the flora of the Alps. The term *flora* means the total plant life of a region. The flora of Ontario, for example, is the entire assemblage of plants, large and small, living within the province.

FIG. 171.—A tropical forest, Yucatan.

Water-loving plants. — All plants require water, but some have become fitted to live with very little, while others require much. In the latter class we find many kinds.

In the waters off the seashore are many humble, flowerless plants — known as seaweeds. If we row our boat over the shallow waters of any pond or lake, we look down upon plants that are perfectly submerged, even though they stand upright and are of considerable height. If we pull one of these stems, we find it limp. It is supported by the water, and does not need a strong, woody stalk, like an open-air plant. It may have poor roots also, since it takes its food less from the soil than from the water. Other plants, like the water-lily, are well rooted, and the stems submerged, but their

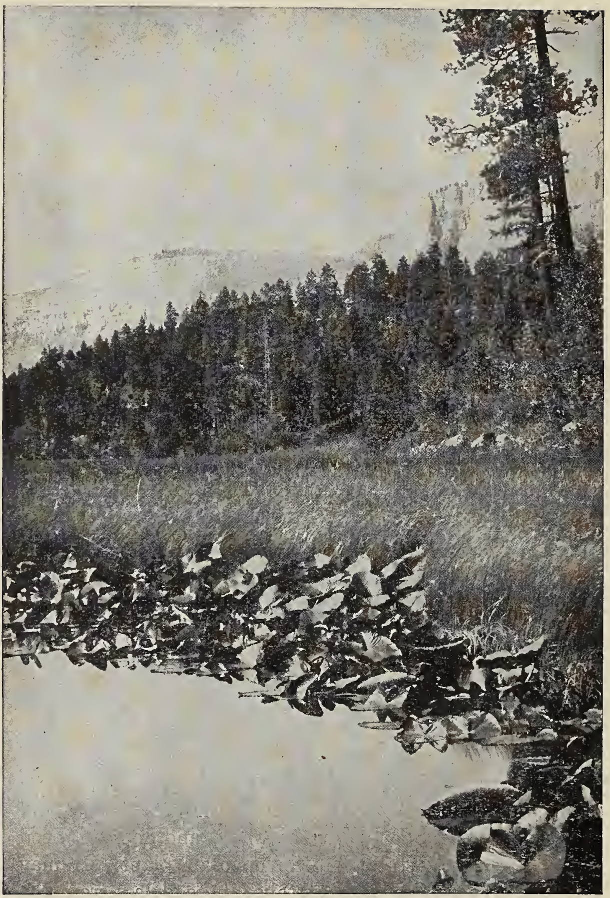


Fig. 172. — A mountain view in Colorado, showing the grouping of plants with reference to water. In the lakelet are yellow pond-lilies, then a belt of swamp-grass, a belt of shore bushes, and finally a pine forest on firm, dry land.

leaves rest on the water, and their blossoms rise a little above it. Multitudes of lowly plants are not attached, but move or float free in the water.

Swamp plants root in water or very wet earth and rise more or less above the water surface. Reeds, rushes, and cat-tail flags are good examples of these, and may be seen on the borders of any pond. There the conditions of plant life are about halfway between those of water and those of land. In swamps are found the cup-like leaves of the pitcher-plant, the spongy mat of the sphagnum moss, and the fruitful cranberry. Upland trees assume special characters when growing on swampy ground. The great swamp-cypress of the Southern States is never found on drier land.

FIG. 173. — A tree-yucca on a desert of southern California.

Dry plains and deserts. — As we pass from the prairies, or natural meadows, westwards, we find the plants becoming more scattered and of fewer kinds, consisting mainly of bunch-grasses and low bushes. The region, however, affords good pasturage. But wide ranges of such pasturage are needed for herds, in comparison with well-grassed regions.

Farther south areas of true desert begin in the western United States and extend into Mexico. Ordinary plants could not live in such heat and drought. Some desert plants, as the cactuses, have no leaves to exhale the moisture. Others have only a few small leaves and shed

them in early summer. Yet others, like the larrea, Spanish bayonet, and agave, have varnished leaves, from which there is little evaporation. All stand wide apart, so that each plant may have a large patch of soil to store for it the scanty rain, and some send their roots to great depths.

Animals of North America

We have grouped the plants mainly according to the conditions in which they thrive. It is not so easy to do this in the case of animals, for while plants are generally attached to the soil, animals often range freely over long distances. But animals, too, are dependent on climate. Some dwell on the ground, others in the soil, and yet others move freely in the air. Many can live only in the water, and some, like the frog, or the beaver, are at home in the water or on the land, dividing their lives between the two.

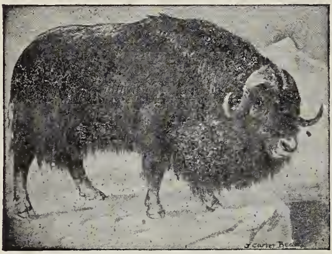


Fig. 174. — The musk-oxen inhabit the tundras and barren grounds of the far North.

Animals of the North. — On the tundras of Alaska and northern Canada are polar bears, arctic wolves, foxes and hares, lemmings, and, at the east, herds of musk-oxen. Most of these have whitish fur, so that they are not easily seen against a background of snow. The barren-ground caribou, closely resembling the Lapland reindeer, roams the country in vast herds. In neighbouring forests, brown and black bears abound, with the moose, woodland caribou, and lynx. The fisher, otter, marten, and mink are still numerous, though reduced by long hunting for their furs. The beaver is still common in some parts of our

country. "This very intelligent animal is the chosen emblem of Canada, for it is at home in the woods and water" (Dawson).

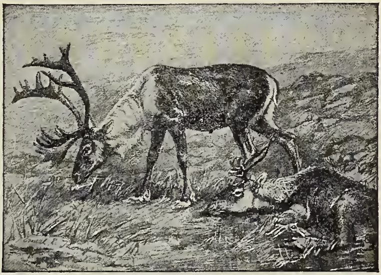


FIG. 175. — The woodland caribou inhabits the forests of Canada and Alaska. (Copyrighted by Forest and Stream.)

At least 600 kinds of birds live in Canada, most of which spend the summers and breed there, but escape the ice and snow of winter by flying southwards. As we might expect from the wide forests and thousands of lakes, ducks, geese, and other water-fowl are found in countless numbers.

FIG. 176. — The moose lives in northern forests. (Copyrighted by Forest and Stream.)

Animals of the temperate regions. — These regions include southern Canada and nearly the whole of the United States. They include also great differences of animal life, if the mountains and the plains, the North and the South, are compared. In the forests of the West live elks, and bears, black, brown, and grizzly; about crags and peaks climb mountain sheep and mountain goats; and antelopes roam the open lowland. All these large animals are less abundant than formerly. Buffa-

loes once ranged the Great Plains of Canada and the United States in millions, so that the land was sometimes black with them. With ruthless hand man has destroyed them, for sport or for the sake of their hides, and so we have a striking example of how man is changing the animal population of the world. The Canadian Government now owns two herds, about one thousand in all, in Alberta, and there are some hundreds of the animals at large in the Peace River district. These, with the exception of a few in various parks and gardens throughout the continent, are the sole survivors of the once countless herds that dotted the prairies only a very few years ago. The destructive jack-rabbits and gophers of the plains are less worthy to survive, but better able to hold out against the attack of man. Bears and wildcats are found in all the forests of the East, and deer, under the protection of the game laws, are abundant. In the northern woods more than 10,000 deer are annually killed.

Fig. 177. — The antelope, or pronghorn, occupies open country on the Great Plains and westwards. (Copyrighted by Forest and Stream.)

The southern lands. — Here the animals, like the plants, change to tropical kinds. The tapir, jaguar, and many monkeys inhabit Central America and parts of Mexico. Armadillos and peccaries flourish as far northwards as Texas, and opossums north-eastwards to New York. Brilliantly plumed birds and venomous serpents tell of more

southern latitudes. Serpents of all kinds diminish towards the north, and are unknown in Alaska and far northern Canada.

We must not omit the most abundant of all animals, the countless insect hosts that swarm from farthest north to farthest south. So, too, all fresh waters are full of life. Lakes and rivers teem with fish, and even the soil is honey-

FIG. 178. — Buffaloes coralled and at peace. Courtesy of *The Toronto Globe.*

combed with the paths of earthworms or burrowing moles, gophers, woodchucks, and prairie-dogs. The continent is filled with animals and plants on its lands, in its soil, in its waters, and in the atmospheric sea that rests upon it. Each condition of temperature and each sort of abode has its own groups of living things.

We shall now study the principles that are illustrated by the plants and animals of our own or of any other continent.

Geographic Conditions of Life

Temperature. — Neither plants nor animals can ordinarily live and be active in temperatures below 30° or

above 120° F. They may for a time *endure* greater extremes, as when plants survive the low temperatures of winter or a man toils in a drying-room of some factory. Certain arctic animals are protected against great cold by coverings of fat and fur, and certain lowly plants live at higher temperatures in the waters of hot springs, but the range of 90° above given is all that life can usually endure for a long time. As we have seen in studying the life of our own continent, the range is not the same for all forms; serpents and monkeys cannot live in the arctic zone, nor polar bears and reindeer in the far South. Cotton belongs in the Gulf region of the United States, corn on the prairie, and wheat, overlapping the corn, will thrive in the far

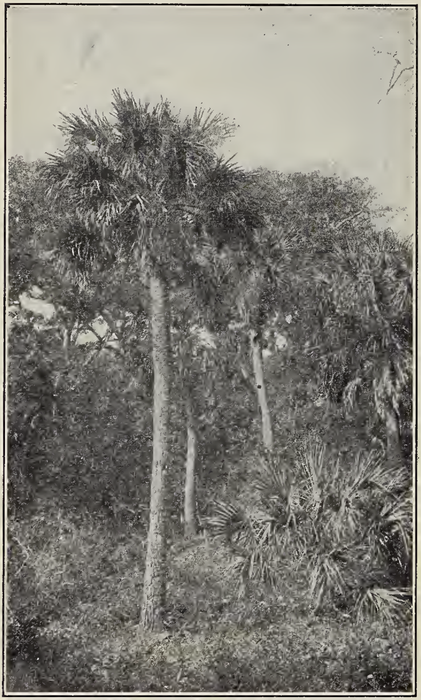


FIG. 179. — A palmetto grove.

north of Canada, in regions too cold for the taller cereal. The life depends on the latitude, because the latitude determines the amount of heat. At the foot of the Rocky Mountains is a mild climate, with bushes and cactus on the plains, with cottonwood along the streams, and with grain, alfalfa, and abundant fruits wherever the land is cultivated with the aid of irrigation. Up the mountainsides are evergreen trees. Beyond the trees are alpine flowers, and above the flowers, rock, snow, and chilling winds. The same story is told if we ascend Mount Etna, the Alps, or any other lofty mountains rising out of a warm country. All grades of temperature, to those of arctic climes, characterize the different parts of a great mountain. Thus altitude vies with latitude in deciding how much heat a place shall have, and what plants and animals shall live and thrive. By shedding their leaves, or by the annual death of the open-air stem, plants may endure great cold in winter. By natural or artificial covering, animals, including man, provide for extremes of temperature; but heat and cold decide largely what creatures shall fill a region.

Water. — No life can be carried on without water. The greater part of all animal bodies, and of many plants, is water. It supplies food, or it serves as a moving fluid to carry food, to all parts of the body — as the blood of higher animals and the sap of trees. We have seen that plants in particular show the greatest differences in respect to water. Some live in the desert, others in places of alternate moisture and drought, others root in moist soil, and yet others are partly or wholly covered by water. The cactus sends out spines instead of leaves, and grows a stocky trunk, to avoid breathing all its water into the dry air. The tree braces itself with many roots, rises high and strong into the air, and requires a moderate supply of water. The water-lily has a limber stalk and a limber leaf,

because the water bears both up, and the water and wet soil below it nourish the plant. With the most heat and the most water we find the most luxuriant plant growth

Fig. 180. — Dam and pond made by beavers, Wyoming. The beaver makes his home in streams and uses great skill in controlling the water to suit his needs.

of the world — the tropical forest. With the most heat and the least water we find the opposite condition — the desert.

The atmosphere. — This is essential to all life. In a general sense all creatures "breathe" the air. The higher animals have various devices, such as lungs and gills, by

which they take in large amounts. Man and the other warm-blooded animals use by far the most, but all lowly animals and all plants must have air, and have some means of absorbing it. This is true even of those that are covered by water, and at great depths. At the bottom of the sea, for example, air is present, though in minute quantities. The roots of the swamp-cypress illustrate a special

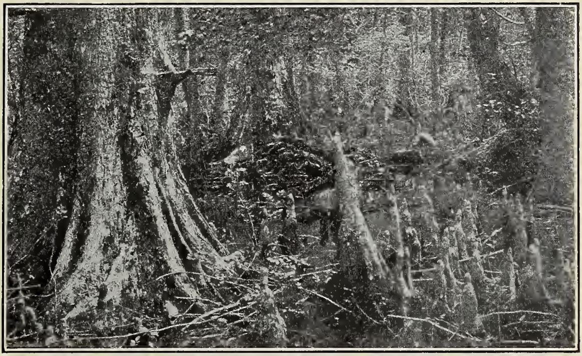


Fig. 181.—A cypress trunk and cypress knees in the Dismal Swamp, Virginia.

device. They are in submerged soil, and send up short, blunt extensions, known as *knees*, above the water surface. If the water is raised to cover the knees, the tree dies, for it is the work of these parts to receive air, which otherwise cannot reach the roots.

Light. — This is required by nearly all life and by all high forms. The higher plants cannot live without it; submerged plants survive with a partial supply. The dependence of plants on light is illustrated by the pale and feeble growth of vegetables in a cellar, even though moisture and heat be fully supplied. Thus we may explain the appearance of close forests, in which each tall, bare

trunk bears a canopy of limbs and leaves like an umbrella. As the tree grows, the lower branches, condemned to the shade, die and fall off, while the top branches thrive in the sunlight. The arrangement of branches on a trunk and of leaves on a branch is such as to expose the most leaf surface to the sun. Exceptions to the general rule are found in burrowing creatures, like moles and earthworms; in cavern fishes and cavern insects, surviving for generations in the darkness, and partly or wholly losing their eyes for lack of use; and in creatures in the depths of the sea, where sunlight does not penetrate, and darkness is relieved only by such phosphorescent glow as their own bodies can furnish.

Soils.—The plant groups on land depend directly on the soil, in connection, of course, with the supply of heat and water. Some soils contain calcium carbonate, others are of clay, and some are almost wholly made up of sand. Sand supports but a partial covering of plants, as the scant grasses and scrubby pines of dunes. The nature of the soil also controls the water supply. Sand parts with water too easily, while a clay soil holds it so tenaciously that artificial drainage by ditches and tile is often needed.

Climate. — This, as we have seen, is determined by many conditions of heat, moisture, and seasonal change, and plants and animals in any region must adapt themselves to these conditions, or migrate, or perish. Some plants, as certain mosses or lichens, may dry up entirely in a period of drought, and revive when moisture comes again. Many survive the winter by maturing, in the autumn, seeds which lie in the ground and sprout in the spring. Others, as many bulbous plants, die down to the surface of the ground, and the underground stem lives, to start the growth of the next season. Broad-leaved trees drop their leaves in winter, and quickly put them on again with the

renewal of warmth. Evergreen trees have small, tough, enduring leaves, which are proof against the frosts of winter. Some animals lie dormant through the winter, neither eating food nor wasting the tissues of their bodies by activity. Birds, whose swift flight gives them independence, adapt themselves to the changes of season by migration to remote regions, all save those, like the prairie chickens of Manitoba and Saskatchewan, which have accustomed themselves to the pinch of winter and to living upon buds and other supplies that do not fail.

Other animals and plants. — Heat, light, and air are hardly more important to a living form than the animals and plants by which it is surrounded. Animals find in other animals their friends and foes, and of plants we may truly say the same. Not less is it true that animals and plants influence each other, helping or destroying. Some illustrations of these relations will be given as we proceed.

Environment. — All surrounding nature is important to the plant. The earth, the sun, and sky, and all living things about it, make up what we call the *environment,* which is only a scientific word for the total surroundings of an animal or plant. We have just been studying the elements or parts of environment — namely, temperature, water, atmosphere, light, soil, and other living things. The environment largely but not wholly decides what a plant or animal shall be.

The tendency to spread. — Single plants usually ripen many seeds, and some plants mature them by hundreds or thousands. We may say, in a figurative way, that every plant tries to occupy as much ground as possible, taking possession wherever there is an opening and pushing out into wider fields, so far as soil, moisture, and other conditions are favourable. The same is true of animals. Thus the buffaloes multiplied until they virtually possessed the Great Plains. If a single pair of birds should be placed

in a favourable region and no accident should happen to them or to their offspring, their descendants would in a few years be numbered by thousands and spread over a wide field. In British Columbia, the pheasants of Vancouver Island and the mainland near Vancouver have sprung from a few brace imported from England about thirty years ago.

The struggle for existence. — Thus we see how, if left to itself, any animal or plant would take possession of all the land or water where it could live, if it met no impassable barrier. But the space is limited, and so each group of plants, as well as each individual, has to contend with every other. The oaks cannot fill the forest because the chestnut, ash, and maple are there. In a thicket of young maples, not all can grow up to be large trees. Those will win which have the best roots, the deepest soil, the best exposure to the sun, or suffer no injury from beast or man. Thus we explain what is meant by the now common phrase, *struggle for existence.* It is not usually a conscious strife, but it is the silent contest going on among competing plants and animals. Fishes produce vast numbers of eggs, part of which are devoured or otherwise perish, while the remainder hatch. But of the multitudinous "fry" only a small part arrive at maturity. Many die of accident, or from failure to get food, or fall a prey to other fishes, and out of such a "struggle" only the strong or the fortunate reach full size and live to their natural limit. In some regions the white oaks are said to be falling behind in the struggle with other oaks, because their acorns are more prized by squirrels and diligently sought by them. Thus by an innocent preference of the squirrel, one kind suffers and the others win in the struggle. Let us take again the case of the tree. A beech may produce thousands of nuts in a single season. These seeds are eagerly gathered by forest animals. If

they escape this fate, they may germinate and drive a root into the soil. But even then, in the thick of the forest, the chances are vastly against the sapling. Taking the seeds of plants and the eggs and infant offspring of animals, especially of lowly sorts, only one in many thousands is likely to produce a mature life.

Migration. — Animals and plants often succeed in the struggle for existence by migrating. All plants scatter their seeds somewhat, and some strew them broadly. The dandelion provides them with plumes that the wind may carry them, the burdock hooks them to the hair of animals, and there are many other devices. So each plant tends to increase its range and spread as widely as it can find suitable environment. When the cold of the Glacial period came on, each kind of plant found life harder at the North and easier at the South, and so, in the course of generations, its range was reduced on one side and extended on the other. Individuals were killed, but the race gradually migrated towards the south. The plant species which could easily send seeds southwards survived, and any which could not migrate perished. This is the sense in which fixed plants can migrate — that is, from generation to generation. Land animals and free-swimming oceanic animals can migrate as individuals, and the birds, as we have seen, for the greater part are in the habit of periodic migration.

Helps and hindrances to migration. — Some of the devices that favour the spread or migration of plants have been noticed. Such are the hooks of the burdock and the plumes of the dandelion. Other seeds have a hard covering which protects them against destruction in the crops of birds, and they may thus be dropped after being carried long distances. Seeds embedded in soil or mud are carried on the hoofs of beasts or the claws of birds. Since man has come upon the earth, multitudes of seeds —

some good, some bad — have been diffused over the earth by him. Such is the so-called Russian thistle, whose roundish tuft of branches breaks off at the ground and is rolled and driven widely by the winds over the prairies. The restrictions upon the importation of fruit, meat, and other articles, by various nations, illustrate the human agency in distributing the germs of life.

Floating timber and roots may transport seeds, plants, and even small animals, for long distances down rivers, and even across seas. It has been shown that some seeds may live after long journeys in sea-water. This helps to explain how new islands in the ocean obtain a covering of plants. As we have seen, swimming and flying animals have an advantage. The beasts of continents cannot reach remote islands unless carried there by man. But the birds are there, because they have the means of travelling over the waters, being often blown out by storms, and alighting there for refuge.

Zoological regions. — Naturalists have shown that the *faunas* or animal groups of different parts of the world may differ greatly from each other even though conditions of climate and surface are similar. South America has hundreds of genera of vertebrate animals not found elsewhere. Among these forms are sloths, armadillos, American monkeys, the jaguar, and the tapir; while there are few hoofed animals, no antelopes, and no native horses, oxen, goats, or sheep.

Africa, on the other hand, has a vast development of antelopes, no tigers or bears, but zebras, quaggas, lions, leopards, many apes and monkeys, including the more manlike forms, and at least two forms found nowhere else, the hippopotamus and the giraffe. Australia is still more peculiar, lacking such common orders as carnivora, ungulata, and insectivora, and showing abundant representatives of the kangaroo and duckbill, primitive

mammalian forms of which the opossum is the only one found out of Australia. These three continents, South America, Africa, and Australia, are separated by wide barriers of deep water, and owing to prolonged isolation, their animals have become modified and special, those of Australia most of all because not near to any great land.

The animals of most of North America, of all northern and central Europe, and of much of Asia have close resemblances and are often of the same genera as many animals of Great Britain and Japan. These facts point to free migration among all these northern regions by formerly existing lands in the North Atlantic or by floating ice. By the latter means polar bears have been carried to Iceland, and reindeer across Behring's Strait.

This distribution depends on migration. If uninterrupted, animals are similar over wide areas; if checked by deep or wide seas or lofty mountains, special groups develop. The longer the barriers have existed, the greater are the differences that have arisen. The mammals of Great Britain are like those of the continent. They could not swim the English Channel, and hence it is regarded as certain that the channel is young, and that the present islands were once a part of the continent. Many extinct animals of Europe are like existing animals of Africa, and it is thought there was land connection across what are now the narrower parts of the Mediterranean. The Galapagos Islands have animals quite different from those of South America, being separated by an ocean barrier of seven hundred miles. The Azores are less special, their animals being like those of western Africa and Europe, though the birds show more kinship than the land mollusks. Lands serve as barriers between seas, and hence the ocean forms differ on opposite sides of the Isthmus of Panama. There is some likeness, however, and this shows that the waters have sometime crossed where the isth-

mus now lies. So, too, the life of the Red Sea is not like that of the Mediterranean. These few illustrations serve to set forth the main conditions and principles which control the grouping of animals throughout the world.

Dependence of animals and plants. — The animal and plant kingdoms belong to each other in many ways. First, we have the familiar fact that most of the higher land animals depend on plants for food. And beasts of prey, in devouring other animals, depend indirectly on plants for life. Vegetation is the only means by which the minerals of the soil can be changed into food for land animals — insect, beast, or man.

We have seen that by direct carriage of seeds or roots, animals foster the wider distribution of plants. But the botanist and zoologist know of many more intimate and curious ties that bind plants and animals together. Insects are protected by taking on certain colours, as the green of forest or meadow. Worms may mimic the colour and even the forms of branching twigs, and thus escape enemies. The tiger is not easily to be seen in the jungle, because its stripes confuse it with the upright lines of light and shadow of luxuriant plants.

We find also that insects and flowering plants have much to do with each other. Many plants would never be fruitful if insects did not drop the pollen of one flower upon the pistils of another. And insects and plants have become adapted to each other by this means. Some insects seek the pollen itself, and others seek the nectar of the flower for food, but in any case the result is the transfer of the pollen. Darwin describes a red clover which could not live without the visits of bumblebees; the honeybees can not reach deep enough into the flower tubes to get the nectar. Hence any enemy that should destroy the bumblebees would make it impossible to raise this kind of clover.

Life of the ocean. — Some facts have been learned in previous chapters. The ocean has its regions and groups of forms as well as the land. Deep water is a perfect barrier to shallow-water forms, and if they should migrate along the shores they might find warmer or colder water that would be fatal to them. Corals belong in warm seas, walruses thrive in northern waters, and each is as characteristic of its zone as palms and polar bears are of the land zones. The whale is a great specialized mammal, whose ancestors are believed to have lived on the land. It has developed its fore limbs into paddles and its tail into a powerful rudder, but has only partly become fitted for life in the water, for it must come to the surface to breathe. It has a wide range in the sea, but its numbers have been reduced by man. A whale was, in the autumn of 1901, reported as having strayed up the St. Lawrence as far as Montreal.

Fig. 182. — Sea-lions, Santa Catalina Islands, California. Though these animals are thoroughly fitted for the sea, and subsist on cuttle-fishes, it is thought that their remote ancestors lived on the land and resembled bears.

Oysters, clams, scallops, and other so-called shell-fish inhabit the shallow waters near the shore. These shelled creatures (mollusks) exist in enormous numbers and have shells of great variety of form, especially in tropical waters, where ornamentation of form and colour has its highest development. With them are starfishes, thorny sea-urchins, and the more active lobsters and crabs. The product of the seas most important to man is the fish.

The shoal-water fishes and the deep-sea fishes furnish the study of a lifetime to any one who would know them well.

The abysses of the sea are not barren, although they are less populous than the upper waters. It is not easy to picture the conditions of life which there reign. There almost complete darkness prevails; hence some deep-sea fishes have large eyes, others have none. The supply of

Fig. 183. — Crabs living in shallow water of the ocean; the kelp crab, in upper part of figure; to the left the edible crab; and to the right the shore crab.

air is small, hence vitality is low. There is no change of day and night, and no alternation of seasons. All creatures there exist under great pressure; the deep sea offers the one environment which may remain without essential change throughout geological ages. A few living forms have been found in deep seas which closely resemble ancient fossil forms, but, as a rule, the inhabitants of the ocean depths are the descendants of shallow-water ancestors which wandered into deeper waters.

Let any one go into what we call the silence of forest or open field and watch and listen. It is a world of

sights and sounds, of living things. Or let him wander by the sea-shore, and look into the pools that the ebbing tide leaves, or see what the waves cast up. The sea is full of life also.

If we would know something of the living world, and would understand what it means, we must also learn that all creatures have come down from a remote past, and that the ancestors of herb and tree, of mollusk, serpent, bird, and horse, are buried in the rocks. This opens the realm of geology, which ever forms the background of geography.

CHAPTER XVI

GEOLOGICAL HISTORY OF CANADA

In studying this volume the student has seen the land forms and other features of the land and sea as they are at the present time. Such study belongs to geography; but we have also seen that geographic features such as a plain, a mountain, a river valley, or a formation of sandstone are due to forces which have been for a long period at work. We can imagine a time far in the past when the plain had not been formed, when the mountain did not exist, when the grains that now compose the sandstone were solid parts of an older rock in a different place. The very place of the lands which the geographer now studies may have been covered by sea waters in those distant times.

When we decipher these ancient changes, and try to see how, during long periods, they have led up to the earth as it is to-day, we are pursuing the study of *geology*. In this chapter we seek to learn enough of the geology of Canada to throw light upon its physical geography. It will not be possible to go far, for geology is in itself a great science, and the student who would know it well must pursue a course of study in it, and then take up the growing literature of the geology of Canada, especially those volumes and maps which for many years have been in preparation by the members of the Geological Survey. Indeed, these geologists have been also geographers, for they have been compelled to explore and map a great wilderness, in order to study and record its geology.

The lands of North America in the ancient geological times were, as a rule, less extensive and much more broken than now. In some periods there was a great archipelago occupying about the place now filled by our continent. At other times North America has been a more continuous land area, but with great interior seas or extensions of the adjoining oceans, areas in which there were salt waters, marine animals and plants, and in which limestones, shales, and sandstones were formed. These rocks contain fossils or petrified shells, corals, or bones, which prove the former inroads of the sea. Sometimes, as in the coal beds, remains of animals and plants belonging to dry land or freshwater marshes, lie between rocks of oceanic origin, thus proving that the region was now sea and now land.

The North American continent has developed from a kind of framework or skeleton into the present wide and solid land. The *Archæan*, the most conspicuous area in the Dominion of Canada, is found inclosing Hudson Bay, and extending down to the Great Lakes. It includes all of the Labrador peninsula on the east, and on the west it stretches in a wide belt to the Arctic Ocean. On the south, it nearly surrounds Lake Superior, and forms the north shore of Georgian Bay. To this area belong three-fourths of the Province of Ontario and about half of all Canada. The rocks of this and similar regions, the world over, are called *Archæan*, because they are primitive, or very old. The geologist does not know that they are actually the oldest rocks which have ever formed part of the crust of the earth, but only that they are the oldest now remaining.

It is common to call the largest subdivisions of geological time *eras*, and thus we may speak of the *Archæan Era* as the earliest of the great subdivisions of the earth's history. The rocks of the Canadian area described in the last paragraph are usually flesh-coloured or gray gneisses,

and the gneisses are often pierced or cut with masses of granite. These rocks do not have a definite order, as do the stratified rocks; they contain no fossils and they show by their crystalline condition and in other ways that they were long ago subject to powerful disturbances, being crushed, metamorphosed, broken, and folded, and often receiving intrusions of lavas, or covers of lava or of volcanic ash.

Archæan formations are found across the United States border, in the Adirondacks of New York, the Highlands of the Hudson, and southwards along the entire length of the Appalachians. They also appear in northern Michigan, Wisconsin, and Minnesota, and in patches or narrow belts along the entire course of the western mountains from Mexico to Alaska. Around these centres or along these primitive axes the later formations have gradually built up the present surface of the continent.

The older and more strictly Archæan rocks are often known as *Laurentian.* Associated with them in Canada, and in other parts of the world, are rocks somewhat younger, but still very ancient and much disturbed and changed, to which the name *Huronian* is given. Some are quartzites, or metamorphosed sandstones, and others slates, and all are often associated with ancient volcanic formations. Indeed, there is ample evidence that in Archæan times there were broad and high mountains, and that volcanic eruptions and earthquakes were common disturbances. Also the Huronian rocks, being originally sediments, show that the sea worked on the borders of the Laurentian lands or invaded them, and eroded the older rocks and made new ones, precisely as it does to-day. It is reasonably certain that there was much life of a low order in Huronian times, so that we find enough outlines to form a general, but truthful, picture of the geography of this very ancient Canada.

Huronian rocks are found in the Ottawa Valley and near Georgian Bay, remnants of formations once more widespread, but now largely removed by denuding forces. It is in formations of this age that northern Ontario offers its important mines of gold, silver, copper, nickel, cobalt, and iron. All the nickel mines are round the edge of a great sheet of volcanic rock near Sudbury. The nickel ore (pyrrhotite) is a compound of nickel and sulphur, The fresh ore has to be roasted in order to drive off the sulphur, whose fumes destroy every green thing in the neighbourhood, making Copper Cliff and other settlements scenes of desolation. More than half of the world's supply of nickel comes from these Huronian hills, the present annual product having a value of $3,000,000.

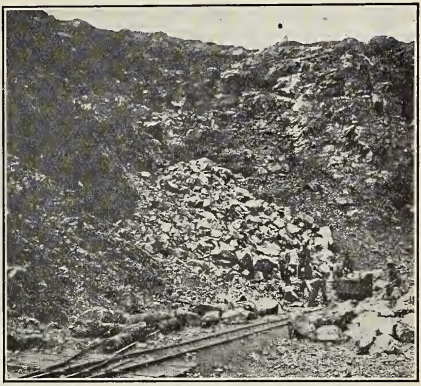


Fig. 184. — The Creighton nickel mine, near Sudbury.

Fig. 185. — A silver mine at Cobalt.

Iron is mined at several points, the most important being near Michipicoten Bay, on the north-east shore of Lake Superior, and Moose Mountain, north of Sudbury. A new mining interest is now established at Cobalt, near Lake Timiscaming, where cobalt and native silver are found in very rich veins. The Huronian rocks of Minnesota and northern Michigan afford supplies of iron and copper which have been mined on a vast scale during recent years.

Canada in the Paleozoic Era. — The next grand division of geological time bears the name *Paleozoic,* meaning the era of ancient life. In rocks of this age the remains of early animals and plants are so fully and perfectly preserved as to give a satisfactory knowledge of the life of those times. Paleozoic time was very long, — how many million years no one knows; for the estimates of geologists, while based often on careful computations, are really only careful guesses. But the era was long enough for rocks many thousands of feet in thickness to form, and for the faunas and floras to change several times.

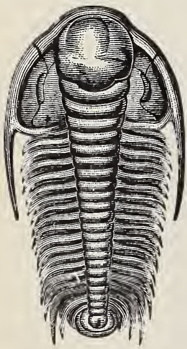


Fig. 186. — A trilobite ½ natural size.

In the beginning of the era there were, so far as is known by remains, no land plants. They may have existed, for there has been small chance that their remains could survive the changes of later ages. There was a great abundance of life in the sea. Sponges, corals, and all the lowly forms or types were included, and all the leading kinds of shelled creatures were present in great numbers. There were hundreds of species of trilobites, representing the modern crustaceans, and fairly early in the era the fishes came in, the first of

the vertebrate tribes that now rule the animal world. About the middle of the era, land animals and plants began to appear, including insects and amphibious creatures fitted both for water and land. In the later part of the era, land vegetation assumed the proportions of forests, and the accumulating woody tissue, preserved in moist places, gave origin to our oldest beds of coal.

The Paleozoic rocks are of special interest in Ontario and the Maritime Provinces, because with scarce an exception they are the youngest formations of all eastern Canada. This fact means further that the eastern half of the Dominion has in the main been above sea-level since the end of the Paleozoic Era. It is all very old land, therefore, and rivers, glaciers, and other destructive forces have had an inconceivably long time in which to mould the land forms and make the soils of this region. A single exception to this condition occurred at the close of glacial times in the submergence of lowlands along the St. Lawrence and on the borders of Hudson Bay.

The principal Paleozoic formations of Ontario extend from Lake Ontario and the upper St. Lawrence to Georgian Bay, and thence south-westwards to the Detroit River, filling the space between Lake Erie and Lake Huron. They are continuous with similar formations across the Great Lakes in the United States. They are not as a rule in a disturbed state, like Archæan rocks, but lie in continuous sheets of sandstone, limestone, and shale, in a nearly horizontal position. Under them is always found the Archæan, which in Ontario comes to the surface on the north edge of the Paleozoic area just described. The Archean constituted a northern upland, while the Paleozoic region was covered by the sea. The rivers brought from the lands at the north the waste which now composes the Paleozoic strata. Among the localities where rocks and many fossils may be found are the cliffs, known as " the moun-

tains," west of Niagara, Hamilton, and Collingwood. Among these fossils are sometimes found the thick plates of the ancient armoured fishes.

To these formations belong the beds of salt found in Ontario. This means that for a period there were desert conditions in this region and in western New York, and shallow bays, partially cut off from the sea, were subject to so much heat as to cause prolonged evaporation and the formation of beds of salt many feet thick. The coming of a rainy season would cause the streams to bring in a layer of mud, and thus we find layers of rock alternating with beds of salt. Later the sea came in with waters of greater depth, and other thick beds of rock were formed above the salt. The youngest rocks of Ontario belong to that period of the Paleozoic Era known as the *Devonian*. In the Devonian rocks there is stored the petroleum, slowly formed, it is generally supposed, from animal or plant remains; and by drilling to still greater depths near Lake Erie the imprisoned natural gas, formed in a similar way, has been set free for use as fuel.

FIG. 187.—Scene at Petrolea, showing oil tanks and derricks used in boring for oil.

Considerable areas of Paleozoic rock are found along the south border of Hudson Bay and on the west side of James Bay. A great belt is also found on the west border of the old Archæan continent, extending through central

Manitoba, north-westwards across Saskatchewan, Alberta, and along the Mackenzie River nearly to the Arctic Ocean. To the Paleozoic also belongs nearly all of that part of Canada which lies south-east of the St. Lawrence River in Quebec, New Brunswick, Nova Scotia, and Prince Edward Island. Newfoundland has large Archæan areas, many volcanic formations, and in the central and western parts of the island there are, running north and south, important belts of Paleozoic rock.

The latest period of the Paleozoic in Canada is the *Carboniferous.* Rocks of this period contain extensive beds of coal, which lie between formations of sedimentary rock such as sandstone, shale, and limestone. The chief occurrence of these rocks is in the Maritime Provinces, in some of the Arctic islands in the far north, and towards the Pacific coast, though in this last region no coal is found of Carboniferous age. The chief coal seams are in Nova Scotia and Cape Breton Island. If a section is examined, we find an under clay containing roots. This is the old soil of the coal swamps and from it rose a luxuriant growth of plants. These were non-flowering, belonging to the group of the cryptogams, distant relatives of our present club mosses, horsetails, and ferns. Standing up above the bed of coal is sometimes found a hollow tree trunk, in its original position, surrounded and filled by sandstone, composed of the sands which drifted about it in those ancient times. Well-preserved ferns and other plants are often found in the shales lying over the coal. Thus the evidence of vegetable growth producing the coal seems complete. The swamps were near the sea border, or in land-locked basins, where a sinking of the lands would let in the sea, and permit the formation of the rock beds which alternate with the coal. As many as seventy coal seams or layers of swampy soil have been found, thus showing many of these alternations.

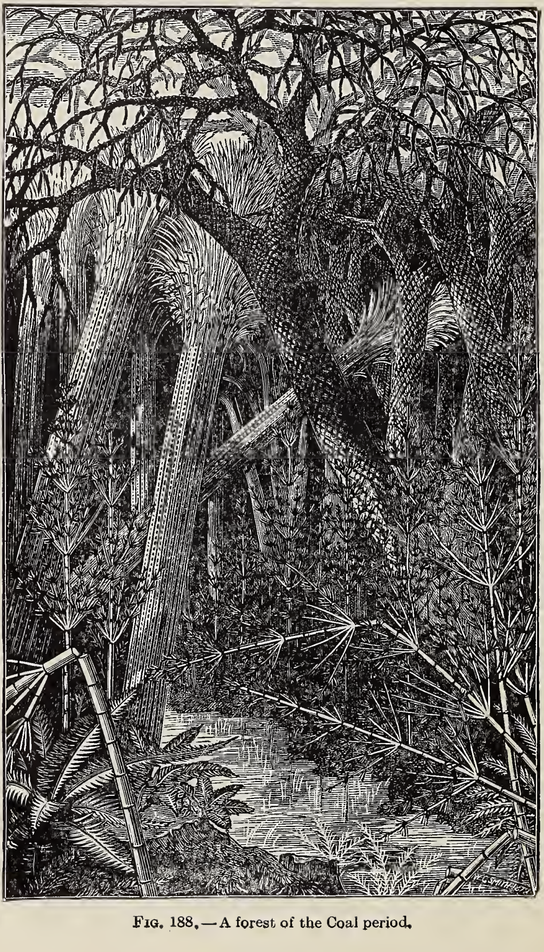


FIG. 188.—A forest of the Coal period.

The coal beds of Nova Scotia have supplied many interesting remains of land animals, such as snails, centipedes, spiders, and scorpions. Vertebrate animals also are found, of the amphibious sort, like the salamander, which begin life with gills, but later develop lungs and become air-breathers.

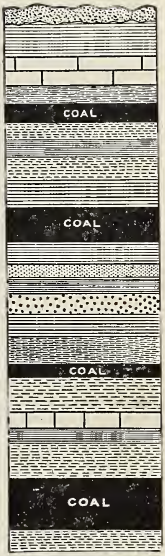


FIG. 189. — Diagram showing coal formations.

Carboniferous formations including coal beds are extensive in the United States, along the Appalachians, in southern Michigan, and in several states of the upper Mississippi Valley. The chief anthracite coal beds of North America are in eastern Pennsylvania, and it is from this locality that we obtain the hard coal used in our furnaces.

The Paleozoic Era was marked at its close by a great series of uplifts and foldings along the Appalachians. There were mountains in that belt in Archæan time, and there were new uplifts during the Paleozoic, but this closing disturbance and uplift mark the beginning of permanent and unbroken land for all of eastern North America. The land surfaces of that time were not in detail like our own, because land sculpture has modified the forms of the land, and the arrangement of the drainage during all of the later eras. Up and down movements and seashore work have also made much change in the shore-lines.

The Mesozoic Era. — This is an era intermediate in its living creatures between the ancient, or Paleozoic, and the modern geological times. The term *Mesozoic* corresponds fairly well to the word *mediæval* as used in human history,

just as Paleozoic compares with our classical period and the Archean may be likened to the period of myth and tradition.

There is almost no record of the Mesozoic Era in eastern Canada, because, as we have seen, that region was above the sea-level, and undergoing denudation throughout the time. There were in the Mesozoic Era, however, extensive sea-waters sweeping over the present Western plains and over much of what is now British Columbia. These regions, therefore, received the waste from the older lands, and widespread Mesozoic rocks were formed. Much of the western half of the Dominion, therefore, and nearly all of the Western plains, belong to this era, including south-western Manitoba, the southern half of Saskatchewan, and the greater part of Alberta.

These plains continue southwards to the Gulf of Mexico, and are of the same general character and geological age, whether found in the Dominion of Canada or in the United States. At Medicine Hat and many other places in this Western region the rivers are cutting deep valleys through the glacial waste and into the soft shales and sandstones of this age. The fact that these rocks are often soft and but little consolidated is one evidence that they are younger than the harder formations of the Archæan and Paleozoic. The vegetation is much more modern, also, and fossil leaves are found, including those of maple, basswood, oak, and poplar, and other trees common in eastern Canada. That the climate was warmer in that region than now, is shown by the presence of figs, magnolias, cinnamon trees, and sequoias.

The animal life, likewise, shows a large advance on that of the Paleozoic Era. The leading forms were reptiles, which showed great variety, and were often formidable creatures. The skeletons of these animals, found in almost perfect condition in Canada and the United States, leave

no doubt as to their existence and their characteristics. Some were sixty feet or more in length. Certain kinds walked on all fours, others strode birdlike on their hind

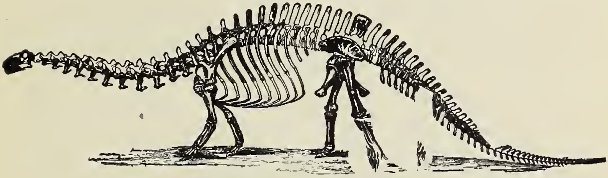


FIG. 190. — Land reptile, Brontosaurus ($\times \frac{1}{120}$).

feet, and browsed on the small trees, which by the aid of their fore feet they pulled down within reach. Some of

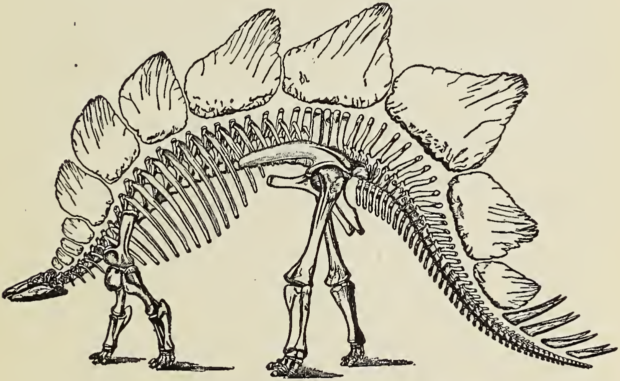


FIG. 191. — Land reptile, Stegosaurus ($\times \frac{1}{80}$).

the biped forms were flesh-eaters and must have been dangerous enemies to all other animals.

Flying reptiles are also found, with batlike wings extended by an immensely long little finger, and other

great reptiles made their home in the sea, their limbs being modified for swimming. Thus, the land, the atmosphere, and the water were ruled by these creatures, while birds had now developed, and some small mammals, the last being insignificant, except as they were the heralds of the great group which was to fill the world in a later era.

The last period of the Mesozoic is known as the *Cretaceous,* a name adopted because rocks of this age in western Europe are in some localities a chalky limestone. They have economic importance in Canada because they contain coal. Indeed, this is the great coal formation of Canada, and its coal areas comprise more than 100,000 square miles. Coal beds of Cretaceous age are found in the basin of the Yukon, beyond the Arctic Circle. The coal of the prairies is of the variety known as *lignite,* containing much water, and hence tending to slack and crumble on exposure. In the foothills of the Rocky Mountains, as at Lethbridge, the quality is, however, much improved; and where the seams are found within the mountains, as in the Crow's Nest Pass, the lignite has been changed into good *bituminous* coal. In Bow Pass near Banff the change has gone still farther, and *semi-anthracite* coal has been formed. These changes were brought about by the pressure and heating due to disturbance in mountain building. Good coal of this age is mined at Nanaimo on Vancouver Island, and is known to exist also at a point near the Skeena River, not far from the route followed by the Grand Trunk Pacific Railroad on its way to the coast.

The Cenozoic Era. — The term *Cenozoic* refers to new or modern forms of life, and during this period both living forms and the lands on which they dwelt assume more and more the appearance which is familiar to us. A great elevation and folding of strata at the close of the Mesozoic took place along the belt of the Rocky

Mountains. It must not be supposed that this range had its present appearance, however, for its heights and forms must have suffered great changes during the long periods of Cenozoic time, through the action of streams, glaciers, and other agents. The elevation of these Western mountains and the general uplift of adjacent regions turned into permanent dry land the region of the great plains, and thus made the extent of Canada and of the continent about what it is to-day.

In the earlier parts of the Cenozoic the climate was still mild far to the north, and in the West luxuriant forests grew where now there is bare prairie. Some important beds of coal have been formed from such vegetation in the Nicola Valley in British Columbia.

There was at times abundant volcanic action, and there are extensive areas of volcanic rock, due not to ordinary eruption through single craters, but to the welling up of lavas, on a vast scale, through rents and fissures in the crust. Sometimes the lavas were forced in between beds of older rock, and sometimes they flowed out over the surface. Similar lava sheets appear on a large scale among the plateaus of the western United States.

Strata of this era may be studied in the Cypress Hills of southern Saskatchewan, where there are ancient lake deposits containing the bones of many mammals, including the ancestors of the horse, pig, deer, camel, and rhinoceros. Preying upon them, as the remains show, was a large carnivorous animal with more powerful jaws than the modern lion. The Cenozoic Era is often called the age of mammals, because these modern forms grew in number and in intelligence, and in the later parts of the era, as now, ruled the world of life. At the beginning of the era, although the mammals were relatively simple and undeveloped, they had points of resemblance to more than one of the orders now living. As time went on, we dis-

tinguish carnivorous species, various plant feeders related to the horse, cow, and deer, rodents related to the rabbit, and elephantine animals, at first having heads bearing horns and very unlike those of modern elephants. Later came the mammoth and the mastodon, close relatives of the elephant of to-day.

The student should guard against the impression that Cenozoic time was short, because its deposits are not ex-

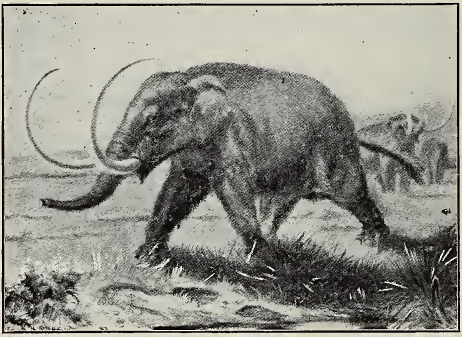


Fig. 192. — A mastodon.

tensive in Canada, and because this sketch is brief. In many other lands the deposits afford wide areas of rock, and the evolution of life was elaborate and prolonged. Besides, the Cenozoic Era properly includes the time of the ice invasion, of which an account now follows.

The Glacial Period. — In the chapter on glaciers the student has already learned a few of the important facts about the ice invasion. We must here review the subject with special reference to Canada as a whole. In almost every part of the Dominion we find beneath the soil of the fields the drift. Of this the most common element is the boulder-clay, containing stones which have not been derived

from the bed-rock below. In Ontario these transported stones have come from the north or north-east. We know this because the drift stones are like rocks found

Fig. 193.—North America during the Ice Age.

in place in those directions, and because the glacial scratches lead back towards Hudson Bay or Labrador. The Glacial Period is the closing part of the Cenozoic, and

is often called the *Pleistocene*, or most recent. From the warm climate of the early Cenozoic there was a change to the Arctic conditions of glacial time.

There were in Canada three great central regions in which the snows and ice accumulated, and from which the glacial sheets flowed out, covering most of Canada and moving far down into the United States. There was a Rocky Mountain field of ice, a sheet of ice in Keewatin and adjoining regions west and south of Hudson Bay, and a Labrador sheet, which extended as far south as New York and Cincinnati and pushed out to the borders of the Atlantic Ocean. About 4,000,000 square miles were covered with ice, though probably not all was covered at one time.

The southern boundary of the ice, which geologists have carefully traced, crosses southern New England, New Jersey, Pennsylvania, western New York, and then follows an irregular course north of the Ohio River. It nearly follows the Missouri River across Missouri, and then runs north-west to the southern boundary of Alberta and British Columbia.

There is good proof of more than one great advance of the ice over southern Canada and the northern United States. The ice melted back for scores or hundreds of miles, and the newly exposed territory regained a cover of plants, and a fresh layer of soil was formed, while the climate was considerably milder. Another advance of the ice-sheet covered up this surface in its turn, and spread more glacial drift over the land. Thus we should expect to find here and there two sheets of drift, separated by soil, leaves, and remains of trees. Fine examples of such *interglacial* deposits are found in the Don Valley, near Toronto, and at Scarboro Heights, where interglacial sand and clay contain leaves and tree trunks, as well as clam shells, belonging to a climate warmer than that of

to-day. It is clear that there were first Arctic conditions, then a warm period, and afterwards a return of the glacier. At last the glacier melted again, and it is at least possible that we are now living in another interglacial period.

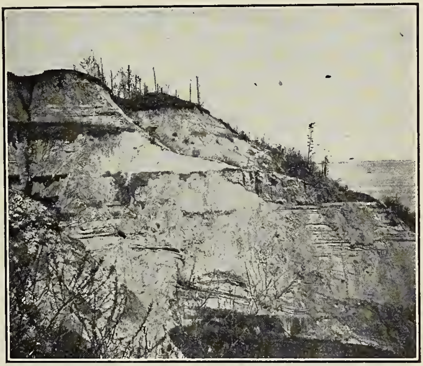


FIG. 194.—Sand and clay of Toronto Formation, Scarboro Heights.

The ice invasion modified the surface of Canada in many ways. These changes we may now take up in review. We have first the great mantle of boulder-clay, sand, gravel, and stratified clays, moved and deposited by the ice and by waters derived from its melting. Below this sheet of drift is the bed-rock, fresh and unweathered and often covered with glacial scratches, and showing by its smoothed and rounded forms the wearing of the glacier. But for the glacier we should find the soils all derived from the underlying rocks, and the top of the rocks would be weathered and decayed, and there would be a gradual passage from soil down to the unchanged bed-rock, as in the Klondike or in the southern Appalachians, or any country which has never been invaded by ice.

There would also be very few lakes, for most of the lakes, great and small, of which we find so many thousands in Canada, are due in some way to the ice. Sometimes valleys were blocked by hills and heaps of moraine,

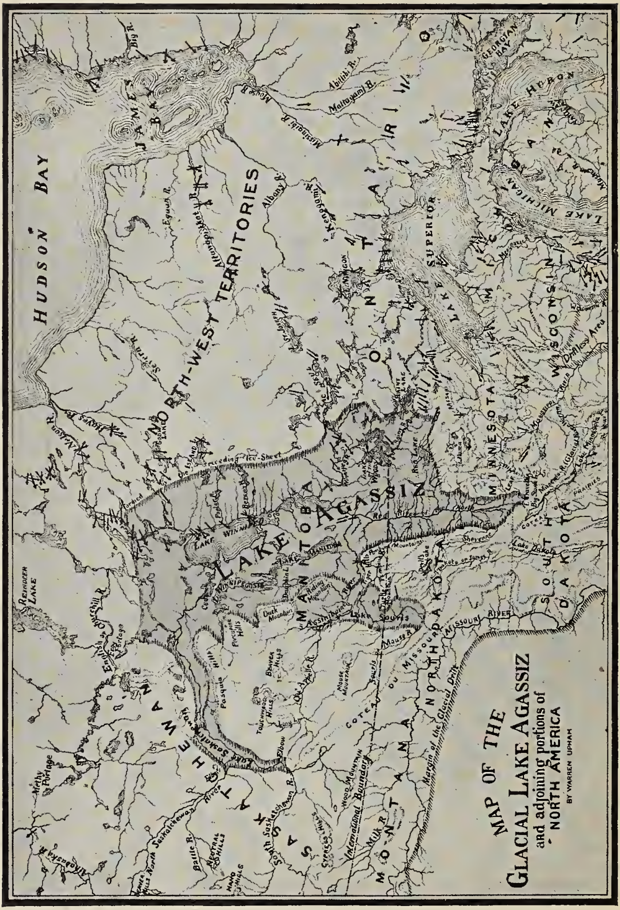

MAP OF THE
GLACIAL LAKE AGASSIZ
and adjoining portions of
NORTH AMERICA
BY WARREN UPHAM
HUDSON BAY
JAMES BAY
NORTH-WEST TERRITORIES
LAKE AGASSIZ
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
GEORGIAN BAY
MANITOBA
MINNESOTA
WISCONSIN
MICHIGAN
ONTARIO
NORTH DAKOTA
SOUTH DAKOTA
MONTANA
SASKATCHEWAN
Receding Ice-Sheet
Margin of the Glacial Drift
International Boundary
MISSOURI RIVER
Lake Dakota
Lake Souris
Driftless Area
Albany R.
Abitibi R.
Mattagami R.
Missinaibi R.
Moose R.
Kenogami R.
Attawapiskat R.
Nelson R.
Hayes R.
Severn R.
Churchill R.
North Saskatchewan River
South Saskatchewan R.
Milk R.
Red River of the North
Assiniboine River
Mouse R.
Sheyenne
Big R.
Equan R.
Reindeer Lake
Methy Portage
Duck Mountain
Riding Mountain
Wood Mountain
Moose Mountain
Touchwood Hills
Beaver Hills
Cypress Hills
Battle R.
Elbow
Lake Manitoba
Lake Winnipegosis
Lake Winnipeg
Red Lake
Mesabi

FIG 195.

and parts of them thus turned into lake basins. It was stated at the close of Chapter VI that the ice probably had much to do with the formation of the present Great Lakes. There are also around these lakes many abandoned shore-lines, — old beaches, — showing that the lakes formerly had higher levels than now. These high waters belong to the time of the last retreat of the ice. Thus Lake Ontario was greater than now, reaching farther into Ontario, and on the south to Queenston, and Syracuse, New York, having its outlet down the Mohawk and Hudson

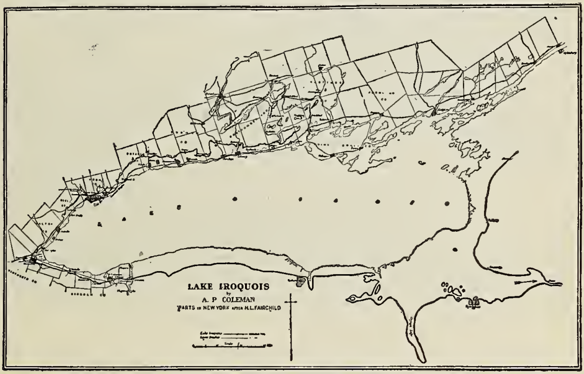


Fig. 196. — Lake Iroquois.

valleys. This greater body of water is known as *Lake Iroquois*. There was an earlier stage when great bodies of lake water drained across Illinois into the Mississippi, and there was a later time when the upper Great Lakes drained by the Nipissing and Ottawa valleys into the St. Lawrence. Farther west, a great glacial lake, known as *Lake Agassiz*, had its outlet where the head of the Red River now is, stretching northwards in Dakota and Minnesota and covering most of Manitoba, reaching to western

Ontario and eastern Saskatchewan. Much wheat land of this great region was formed by the accumulation of muds at the bottom of this lake. There is not space here to name other changes in the Great Lakes, or to explain the order and causes. For these the student must refer to more special works.

We also find in Canada a great number of waterfalls and gorges which are so narrow, steep-sided, and youthful

FIG. 197. — Virgin Falls on the Nipigon River.

as to show that they have been made in recent times. The glacial waste was left so irregularly on the surface as to block up many of the ancient drainage courses. In some cases, as we have seen, lakes were formed, and often the rivers were turned out of their old and well-broadened valleys into new courses, where they encounter rock ledges and give origin to falls, rapids, and gorges. Before the ice age, a great river flowed from the Georgian Bay region past Barrie and Newmarket, reaching the valley of Ontario near Scarboro Heights. The last ice-sheet accumulated a moraine, known to us as the Oak Ridges,

across the ancient channel, so that a range of hills hundreds of feet high now cuts off the upper lakes from Lake Ontario, and forces the water to flow by Lake St. Clair and Niagara to the sea.

Geographic features dependent on geological formations. — Several such present features have just been described as resulting from the ice invasion. Thus we have the lake-bottom soils of Manitoba and southern Ontario, the bouldery cover of much of the surface, the lakes for navigation, and falls and rapids for water power. It is easily seen, also, that all the wilder lands of eastern Canada belong to the Archæan, whose rocks do not form as good a soil, but furnish many valuable minerals, and offer rugged surfaces suited to forests. Nearly all the important cities of Canada, Toronto, Quebec, Montreal, Halifax, Ottawa, and Winnipeg are on the Paleozoic formations. Here are the older settlements and the majority of the population. Vancouver and Edmonton may be named as having a place in regions which are geologically much younger. The wheat lands of Canada are, as we have seen, mainly of Mesozoic origin, covered in some localities by extensive sheets of sediment laid down in glacial waters. The lakes and the indented shore-lines of both the Atlantic and Pacific coasts have also resulted in favourable conditions both for internal and ocean commerce.

A gradual evolution has brought our lands to the present extent and form, and an almost equally prolonged development has given the present population of plants and animals, and has set man himself to take advantage of the vast resources of this northern half of the continent.

CHAPTER XVII

THE EARTH AND THE SUN

Our dependence on the sun. — All thoughtful minds recognize that we upon the earth owe much to the sun, but few realize how complete our dependence is. We receive directly immense supplies of energy in the form of heat and light; and if we take the trouble to trace back to its origin the energy which we see manifested in the various changes on the surface of our globe, we always eventually reach the sun.

The falling water would cease to run if its store were not continually renewed from the clouds, and the moisture of the clouds is transported thither from the ocean by the sun. Our wood and coal and oil, whose energy we use in combustion, were obtained — whether decades or ages ago — from the sun. Animal power is likewise dependent on the sun. The body of the animal is a very ingenious and effective machine which its living inhabitant controls and utilizes for the transformation of the energy contained in food into mechanical or mental energy.

Were the sun's rays cut off for a single month, all life on the earth would cease. Acting through past ages, the sun has produced the numerous and great changes in the surface of our planet, which have been outlined in the previous chapters of this book.

The earth is round. — One of the most familiar proofs of the roundness of the earth is the appearance of a ship on a large body of water. Ordinarily, when an object

recedes from us, we first lose sight of the smaller details of it; but not so in the case of the ship. As it moves away we lose sight of the hull before the masts or the funnels (Fig. 198). The most satisfactory explanation of the phenomenon is that the surface of the earth is curved, and that the bulging portion comes between us and the lower portions of the ship; and as the effect is the same no matter in what direction the ship is going from us, we conclude that the earth is equally curved in all directions.

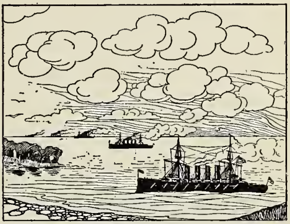


Fig. 198. — The hull of the ship disappears first.

We know, too, that it is possible to travel around the earth; and although this does not prove that the earth is spherical, it does show that it is bounded by curved surfaces.

Like every other opaque body, the earth casts a shadow when the sun's rays fall upon it; and when the moon in its monthly path about the earth enters this shadow, it is said to be eclipsed. Now the form of the shadow, as seen on the moon's face, is such as only a sphere could cast.

But more satisfactory evidence is found in observing the behaviour of the pole star as one travels northwards. At the equator the star is seen just on the horizon, and as one proceeds northwards it uniformly rises, until, if one were at the north pole, it would appear directly overhead. This could happen on no other body than a sphere.

On actually measuring the dimensions of the earth with the greatest care, as is done in a geodetic survey, we find, however, that it is not strictly a sphere, after all.

It is a spheroid very slightly flattened at the poles. The earth's equatorial diameter is 7927 miles, its polar diameter is 7900 miles, that is, there is only a difference of 27 miles between them.

The rotation of the earth. — Daily we see the sun rise in the east, pass across the sky, and set in the west. The moon and the stars move in a similar way, though many people have never observed this. Let us watch some evening the stars towards the north, for several hours. They always remain in sight, and while they preserve the same positions relative to each other (for instance, the "Big Dipper" never changes its shape), they all describe circles in the sky.

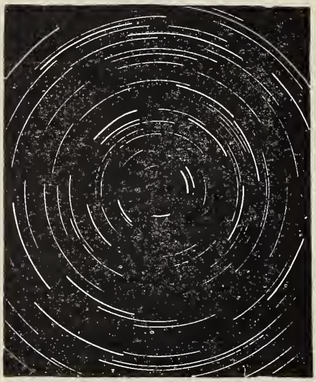


Fig. 199. — Photograph of stars near the north pole. Exposure about 2 h. 45 m. The brightest arc near the centre was made by the Pole Star.

It is interesting to photograph these stars. First, in daylight, focus the camera on a very distant object and mount it firmly. Then point it towards the north, directing the lens upwards at an angle of about 45°. As soon as the stars are out, and it has become quite dark, open the shutter and leave the plate exposed as long as convenient. On developing the plate and making a print, you will obtain a picture like that in Figure 199. From this it is seen that the stars describe arcs of circles, which have a common centre.

Now we must conclude either that the stars revolve about the earth, or that the earth rotates about an axis

which points towards the common centre of the arcs of the circles shown in the figure. In various ways it has been shown that the latter is the true explanation.

The common centre of the circles described by the stars is called the *north celestial pole*, and of course there is a *south* celestial pole. The great circle in the sky midway between these poles is the *celestial equator*. It is the circle in which the plane of the earth's equator cuts the sky.

The sun's apparent motion amongst the stars. — By observing the stars in the neighbourhood of the moon on successive evenings, we easily see that the moon moves amongst the stars; but we cannot make similar observations with the sun, since the stars cannot be seen during the day.

It is quite easy, however, to convince ourselves that the sun does move relatively to the stars. In the first place, the sun is high up in the sky in summer and low down in the winter, which shows that it moves northwards and southwards in the sky. But it has a continuous eastwards motion as well. This can be shown in the following way. Immediately after sunset observe what stars are rising on the eastern horizon. In March the most conspicuous eastern constellations after sunset are Leo and Boötes. A month later these are higher in the sky, and Virgo has taken their place. In the summer Libra appears, and still later Scorpio, while in midwinter Orion and Taurus come up as the sun goes down. The sun thus appears to move continually through the stars.

The sun's apparent path amongst the stars is called the *ecliptic*. It follows the same course year after year, and it requires just one year to complete the circuit.

The earth's real motion. — This motion of the sun amongst the stars was known in ancient times, but we have since learned that it is only apparent, that it is

the earth which really moves after all. A simple experiment will explain how this can be.

Place a lamp on a tall stand in the centre of the room at the height of the eye. Then, keeping some distance from it and facing it all the time, walk slowly about the lamp. Notice how it seems to move round among and pass by the objects on the wall. Observe, too, that it appears to travel in the same direction about the room as you do, and to make a complete circuit in the same time. Now imagine yourself to be the earth, the lamp to be the sun, and the objects on the walls to be the fixed stars. The horizontal plane through the lamp and the eye will represent the plane of the ecliptic, and a complete circuit about the lamp will correspond to a year.

The earth's orbit. — The actual path followed by the earth about the sun is called its *orbit*. In form it is an ellipse, having the sun at one focus, but it does not differ from a circle nearly so much as the ellipse shown in Figure 200.

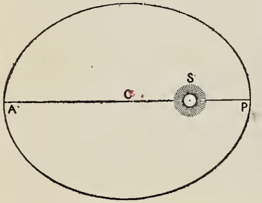


Fig. 200. — The orbit of the earth is an ellipse, though not so elongated as this one.

Let C be the centre of the ellipse, and S the sun in one focus. That point P nearest the sun is called *perihelion*, and the point A farthest away is called *aphelion*. In the earth's orbit the distance from C to S is but $\frac{1}{60}$ of that from C to P. When drawn on any ordinary scale, the orbit would not be distinguishable from a circle.

The greatest diameter AP is 186,000,000 miles in length, AS is 94,500,000, and PS 91,500,000 miles. Thus at perihelion the earth is 3,000,000 miles nearer the sun than at aphelion. The average of the two is 93,000,000 miles, which is taken as the *mean distance* of the earth from the sun.

The cause of day and night. — When the sun shines upon the earth, one half is illuminated, the other half is in darkness (Fig. 201); to the former portion it is day, to the latter, night. As the earth rotates uniformly on its axis, different portions of the earth come in succession into the light, and we have our regular sequence of days and nights.

FIG. 201. — The cause of day and night.

Inclination of the earth's axis to the plane of the ecliptic. — If the earth's axis were perpendicular to the plane of its orbit, it is evident that the sunlight would always extend from pole to pole, that our days and nights would always be of equal length (each 12 hours), and that any portion of the earth's surface would continually receive the same amount of heat and light. In this case there would be no change of seasons, except what little change might be produced by our being slightly nearer the sun at one time than at another.

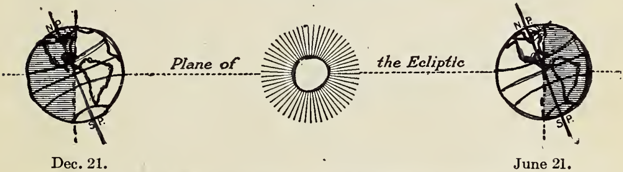
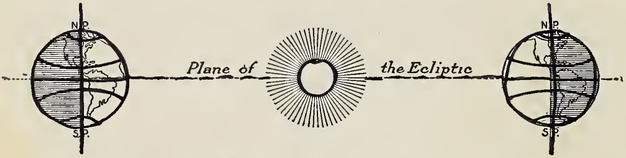


FIG. 202. — Showing the inclination of the earth's axis to the plane of the ecliptic.

The axis, however, is inclined from the perpendicular at about $23\frac{1}{2}°$. In Figure 202 are shown two positions of the earth in its orbit. In that to the left the north pole is turned away from the sun, and in consequence the sun's rays fall short of it by $23\frac{1}{2}°$. At the same time

they shine beyond the south pole by a like amount. The circle about the north pole with radius 23½° is called the *arctic circle;* that about the south pole, with equal radius, the *antarctic circle.* When the earth is in the first position shown, all places within the arctic circle have continuous night; those within the antarctic circle have continuous day. It will be seen, too, that the sun is directly overhead for all places 23½° south of the equator. The circle drawn parallel to the equator and 23½° south of it is called the *tropic of Capricorn.*

Next, consider what takes place when (six months later) the earth is in the position shown on the right. Here the northern hemisphere is turned towards the sun,



March 21. Sept. 21.

FIG. 203. — The sun vertically over the equator.

the entire arctic circle receives light and heat from the sun, and within it is continuous day, while within the antarctic circle it is continuous night. As the sun shines 23½° beyond the north pole, it is directly overhead for places on a circle parallel to the equator and 23½° north of it. This circle is the *tropic of Cancer.*

Finally, let us consider what must be the condition of affairs midway between the positions shown in Figure 202. It is evident that then the sun will be vertically over the equator and its rays will extend to both poles (Fig. 203). At this time all places on the earth's surface will have 12 hours of day and 12 hours of night.

The seasons. — We can now understand why we have our succession of seasons. In Figure 204 is shown the

way in which the sun illuminates the earth in twelve positions in its annual path, corresponding to about the 21st of each month.

Let us begin with the earth at the *vernal equinox*, about March 21. At this time the sun is vertically over the equator, and its rays just reach to the poles. Hence the equator and all the latitude circles parallel to it are

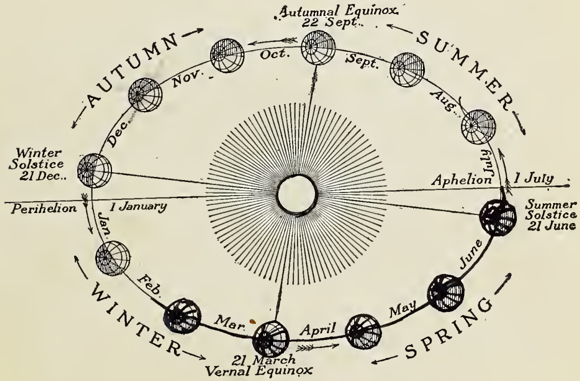


FIG. 204. — Illustrating the production of the seasons.

half within the illuminated portion, and at every place on the earth's surface the days and nights are equal. As the earth moves onwards the sun becomes vertical to points north of the equator, the days in the northern hemisphere lengthen, and the temperature rises. On June 21 the sun reaches its highest point in the sky, being vertically over the tropic of Cancer, and the entire arctic circle is illuminated. The days are now longest, and we receive more heat in a day than at any other time in the year. The sun appears to stand still for a few days before it begins its southwards journey again, and for that reason

this time is called the summer *solstice* (*solstice* means "standing sun.")

Although at this time the northern hemisphere is receiving heat most copiously, it is not the hottest time of the year. We are adding to our store most rapidly, but for a month or more afterwards we continue to receive more than we give out, and the general temperature continues to rise until about August 1, which is therefore the hottest time of the year.

As the earth moves onwards, the period of daylight shortens, the sun's rays fall more obliquely, less heat is received during the day than is given out during the night, and the temperature gradually falls. On September 21 the sun is again over the equator, and we have the *autumn equinox.*

From this time, as the duration of daylight decreases, the earth continues to lose its heat, and on December 21 the sun is farthest south. It is then over the tropic of Capricorn, and the time is the winter solstice. At this time the earth is giving up its heat most rapidly, but our weather is not coldest then. The earth continues to give out more heat than it receives until about February 1, which may therefore be considered as the heart of the winter.

Gradually from this time the sun climbs higher in the sky and the temperature rises. On March 21 it is once more over the equator, and we have the vernal equinox again.

It will be understood, of course, that we have described the changes as they occur in the northern hemisphere. In the southern hemisphere the changes will be similar, but their summer-time corresponds to our winter-time. Summer solstice with them is winter solstice with us.

Thus we see that the changes of the seasons are due to two causes: (1) the revolution of the earth about the sun,

and (2) the inclination of the axis of the earth to the plane of its orbit.

THE MEASUREMENT OF TIME

Meaning of the word "day." — By a *day* we mean the time it takes the earth to rotate on its axis. But the question arises, How can we know when the earth has completed a rotation?

If you tie a weight on the end of a string and allow it to hang freely, it assumes a vertical direction, and the point overhead where the string, if produced, would cut the sky is called the *zenith*. Consider now a plane containing this vertical line and passing through the north pole of the sky. This is our *meridian plane*, and the circle in which it cuts the earth's surface is our *terrestrial meridian*, while the circle in which it cuts the sky is our *celestial meridian*.

It is evident now that the sun and the other celestial bodies as they traverse the sky from east to west will cross, or *transit*, our meridian. As has already been pointed out, this diurnal motion of the sun and stars is only apparent. The earth rotates, carrying us and our meridian with it, and the meridian passes over the heavenly bodies. It is usual, however, to speak of these bodies as transiting the meridian, not of the meridian passing over them.

A sidereal day is the period of rotation of the earth as determined by reference to a fixed star. It is the interval between the moment a star is on our meridian and the moment when it next comes there again. It is about four minutes shorter than our ordinary day. The reason for this will soon appear.

An apparent solar day is the interval between the moment the centre of the sun is on the meridian and the moment when it next comes there again. When the sun

is on the meridian, it is *apparent noon.* If the sun did not move amongst the stars, the solar and the sidereal day would be of the same length. On account of the sun's motion the former is about four minutes longer than the latter.

The mean solar day. — All sidereal days are exactly equal in length, but this is not the case with the apparent solar days. The speed of the earth is not the same at all parts of its orbit, and the orbit is inclined to the plane of the equator; and consequently the rate at which the sun appears to move eastwards in the sky is not uniform. For this reason the apparent solar days are not all equal in length. It has been found that the time from apparent noon to apparent noon is fifty-one seconds longer on December 23 than on September 17. In order to avoid the inconvenience of a solar day of variable length, the *mean solar day* is used. This is obtained by taking the average of all the apparent solar days throughout the year.

For convenience, astronomers imagine an average or *fictitious sun* to travel eastwards along the celestial equator (not the ecliptic) at a uniform rate, making the entire circuit of the heavens in a year. When this fictitious sun is on the meridian, it is *mean noon,* and the interval from one mean noon until the next is a *mean solar day.* These days are all exactly equal in length. They are divided into hours, minutes, and seconds, and this is the kind of time kept by our clocks and watches in common use.

Why a solar day is longer than a sidereal day. — The reason for this will be readily understood by reference to Figure 205. Here O and O' are two positions of the earth in its orbit one sidereal day apart. In the first position it is noon for all places in the illuminated hemisphere on the meridian plane passing through A. Suppose that, on the opposite side of the earth, this meridian

plane passes through some particular star. While the earth has travelled along its orbit from O to O', it has made a complete rotation, and the meridian plane $O'A'$ is parallel to its former direction. Since the star is at a distance indefinitely great compared to OO', the star will again be on the meridian. The sun, however, is in the direction $O'S'$, and the solar day is not completed until the earth has turned on its axis enough to bring $O'A'$ around to $O'S'$. To do this requires about 4 minutes. Thus, while a mean solar day is equal to 24 hours of mean solar time, the sidereal day is equal to 23 h. 56 m. 4.09 s. of mean solar time.

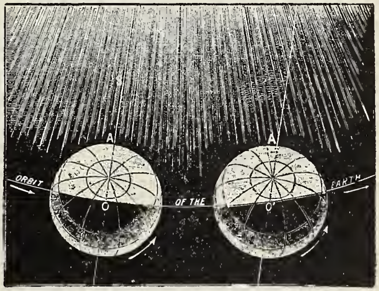


Fig. 205. — Comparison of a solar and a sidereal day.

Equation of time. — The apparent solar time, as we have seen, does not agree exactly with the mean solar time, and by *equation of time* is meant the difference between the two. Four times during the year (namely, about April 15, June 14, September 1, and December 24) the equation of time vanishes, that is, the apparent and mean times then coincide. On February 11 the apparent time is 14 m. 32 s. slower than mean time, while on November 2 it is 16 m. 18 s. faster. These are the greatest differences between the two times.

The sun-dial. — Before clocks and watches became so cheap and trustworthy the sun-dial was much used. The time given by it is apparent time, noon by the dial being the time when the sun is on the meridian.

In Figures 206, 207 are shown two forms of dials. In the former AB is a wire, and CD is a circular metal ring with its plane perpendicular to AB, and having AB passing through its centre. The inner face of the ring is divided into twenty-four equal parts, corresponding to the twenty-four hours of the day. The instrument should be set so that AB is parallel to the earth's axis, and hence with the plane of CD parallel to the equator. The sunlight falls on AB, which casts a shadow on the inner face of the ring, and as the sun moves across the sky the shadow moves about the ring. If the graduations on the ring are numbered, that one at D being XII, it is evident that by observing the shadow the time can at once be determined.

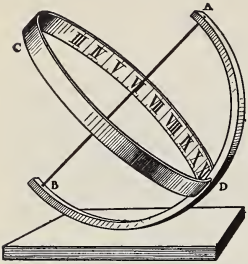


Fig. 206. — A simple form of sun-dial.

In the dial illustrated in Figure 207 the graduations are placed on a horizontal metal plate, and instead of using a wire, the shadow is cast by a piece of sheet metal, called the *gnomon*. The angle made with the horizontal plate by the straight edge of the gnomon should be equal to the latitude of the place, and when the dial is properly adjusted this straight edge is parallel to the earth's axis. The angles on the base-plate, however, for indicating the different hours, are not now all equal; but the manner of calculating them is too difficult for explanation here.

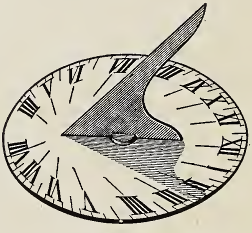


Fig. 207. — The ordinary form of sun-dial.

Having determined the apparent time from the dial, we must add or subtract the equation of time (as the case may require it), and thus obtain the *local mean time.*

Standard time. — When the sun is on our meridian, it is noon to us, and as the sun cannot be on all meridians at the same time, it is clear that different places will have different times. Each place has its own *local time.* Before the days of the telegraph and of rapid and frequent travel, the method of using local times gave rise to no serious inconvenience, but with the growth of railway traffic a change became advisable. A passenger from Montreal on reaching Toronto would find his watch twenty-three minutes fast, while one coming from Winnipeg to Toronto would find his time 1 hr. 10 m. slow. If a railway company set its timepieces to correspond with the local time at one station, there would be a difference between "railroad time" and local time at every other station. To escape the great confusion thus arising, the system of *standard time* was adopted in 1883.

Since 360° of the earth's circumference correspond to 24 hours of time, places separated by 15° of longitude have local times differing by one hour. Taking as our first meridian that passing through Greenwich, the local time at places 75° west will be 5 h. behind Greenwich time; those at 90°, 6 h.; at 105°, 7 h.; etc. In order to apply the system, the whole of Canada and the United States was divided into five belts running north and south which extend $7\frac{1}{2}°$ on each side of the 60th, 75th, 90th, 105th, and 120th meridians, respectively. The first is the Atlantic belt, and all clocks within it show the local time of the 60th meridian, *i.e.* they are all 4 h. slow of Greenwich time. This is called Atlantic time. Eastern standard time is that of the 75th meridian belt, Central that of the 90th meridian, Mountain that of the 105th

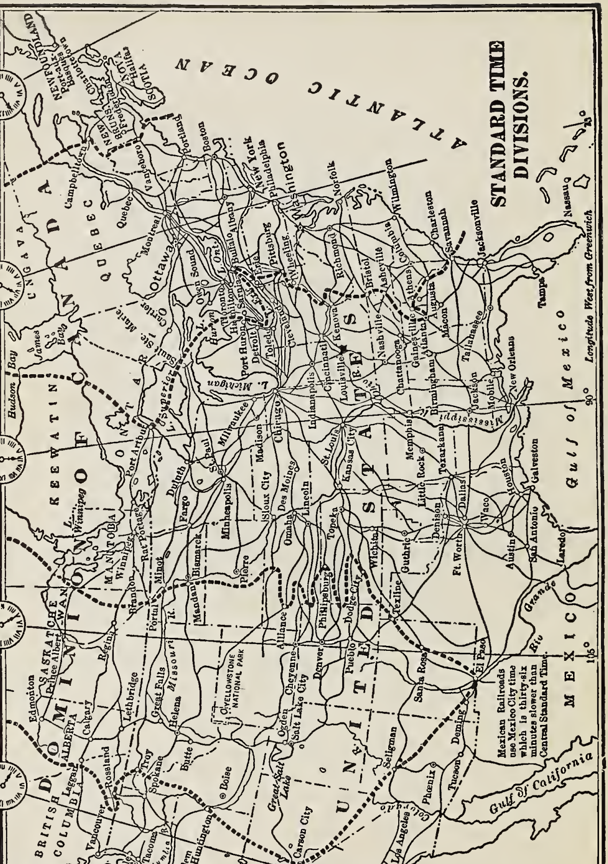


FIG. 208.—Map showing Standard Time Divisions.

meridian, and Pacific that of the 120th meridian. The last is 8 h. slower than Greenwich time.

In reality the railways do not change their time when exactly $7\frac{1}{2}°$ from the standard meridian, but at some well-known place near by. Thus the boundaries of the belts are not exactly north and south lines, but are quite irregular, as shown in Figure 208.

The length of the year. — A year is the time required for the earth to make a revolution about the sun, but as in the case of the day, how are we to know just when the orbit is completed?

Suppose the earth to be at *A* (Fig. 209) at the spring equinox (March 21). At that time the sun is vertically over the equator. The line *SA* joining the centres of the sun and earth will point to some fixed star, and hence its direction in space will be definitely fixed. The earth moves onwards in its orbit in the direction indicated by the arrow, and at length comes round to the spring equinox again. Now if the equinoctial point remained in precisely the same place, the earth would arrive at it and in line with the fixed star again at the same moment. But such is not the case. The equinoctial point has a slow motion in the opposite direction, moving from *A* to the near-by point *B* while the earth is making its revolution. This slight movement is known as the *pre-*

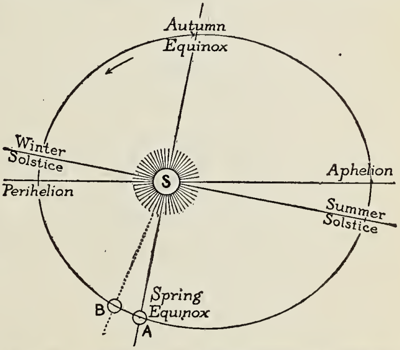


Fig. 209. — Diagram to explain the length of the year.

cession of the equinoxes, and it has been shown to be due to the fact that the earth is a spheroid, not a perfect sphere. It is evident, then, that after arriving at *B*, the new position of the equinox, some further time must elapse before the earth reaches the point *A* again.

The time required to pass from *A* around to *A* again, that is, to make a complete revolution relative to the fixed stars, is called a *sidereal year;* while the time to go from *A* around to *B*, the new position of the equinoctial point, is called an *equinoctial* or *tropical* year. The lengths of these years are: —

Sidereal year, 365 d. 6 h. 9 m. 9 s., or 365.25636 days.
Tropical year, 365 d. 5 h. 48 m. 46 s., or 365.24219 days.

Thus the former is 20 m. 23 s. longer than the latter, each being very nearly 365¼ days.

As our seasons and the general regulation of our lives depend upon the sun's position with respect to the tropics or the equator, the tropical year is the one we use in our chronology.

The calendar year. — For civil purposes it is inconvenient to count fractions of a day in the year's length, and the *calendar* or *civil year* is ordinarily 365 days. But this is about one-fourth of a day too short, and so, in order to balance up, every fourth year an extra day is put in, and the year, which is called a *leap year*, is then 366 days. But it will be seen that the difference between the tropical and the ordinary calendar year is not quite one-fourth of a day (being 11¼ minutes less), and so the addition of an extra day every fourth year more than makes up the difference. For this reason it is found necessary, in the case of centuries, to count as leap years only those divisible by 400. Thus 1700, 1800, 1900 were not leap years, but 2000 will be one.

Latitude and longitude. — An important work of every nation is to explore and map its lands and to sound and chart the seas. The lands cannot be opened for settlement unless they are accurately surveyed, nor can the sea be used as a highway unless its harbours and channels and shoals are so definitely located that the mariner can readily find them.

The readiest way to state the position of a place is to give its *latitude* and *longitude.*

Imagine a series of great circles drawn on the surface of the earth from pole to pole. These are *meridians.* Also draw a series of small circles parallel to the equator. These are *parallels of latitude* (Fig. 210).

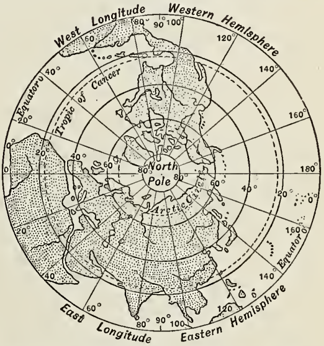


Fig. 210. — Diagram to illustrate the meeting of the meridians at the north pole.

Latitude is distance north or south of the equator measured on a meridian. As the meridians are all equal in length, namely, about 25,000 miles, and as a circle contains 360°, 1° of latitude is a little over 69 miles in length. All places on a parallel of latitude, of course, have the same latitude.

Hence, if we are given the latitude of a place, we know it must lie on a particular one of these parallels. But we must have some method of locating points in an east-and-west direction. This is done by means of the meridians. One must be taken as the line to measure from, and although it is purely a matter of choice, that one almost universally chosen is the meridian passing through

the Royal Observatory at Greenwich, near London. This is called the *prime meridian,* and from it we measure eastwards and westwards 180°. Thus all points in North America are in west longitude and north latitude. On the equator a degree of longitude is about 69 miles in length, but the parallel circles become smaller as we go towards the poles, and so the degrees of longitude become smaller. At latitude 45° a degree of longitude is about 49 miles in length.

Longitude is sometimes stated in hours, minutes, and seconds instead of in degrees. Two places 15° apart have times differing by one hour, and by taking 15° as equivalent to one hour, we can transform degrees into time. As an example, it may be stated that the Meteorological Observatory of the Dominion Government, Toronto, from which the weather forecasts are sent out, has the position: North Latitude, 43° 40′; West Longitude, 79° 23′ 54″ or 5 h. 17m. 36s.

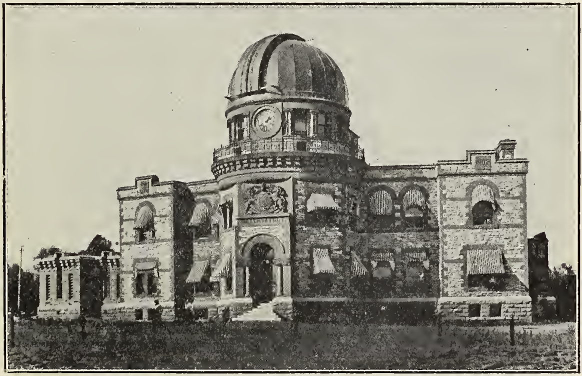
Determination of latitude and longitude. — Latitude is found from observations of the heavenly bodies. When one is at the equator, that is, in latitude 0°, the north pole of the sky is just on the horizon, and as we go northwards it gradually rises. At latitude 45° its elevation is 45°, and on reaching the north pole of the earth it would be directly overhead or at an elevation of 90°. Thus its elevation, or altitude, is equal to the latitude of the place.

It is well to know, however, that the *Pole Star* is not exactly at the north pole. It is about $1\frac{1}{4}$° away from it, and it describes a small circle about the pole (see Fig. 199). Suppose, now, we take observations of its elevation when it is highest in the sky, or " at upper culmination," and again twelve hours later, when it is lowest, or " at lower culmination." Then it is clear that one-half the sum of these measurements will be the elevation of

the pole, and therefore the latitude of the place. Any other star near the pole can be used in the same way.

On board ship the navigator usually finds his latitude by observing the elevation of the sun at noon. In this case he must be furnished with the position of the sun above or below the equator at the time of the observation. This information is obtained from the *Nautical Almanac*.

Determination of longitudes is more difficult. It is made by comparison of times. A ship carries one or more chronometers, carefully regulated, which keep Greenwich time. By observations the officer finds his own *local time*, and a comparison of the two times will give the longitude from Greenwich. On land the difference in time is found telegraphically, and the difference in longitude thence deduced.



Dominion Astronomical Observatory, Ottawa

CHAPTER XVIII

THE SOLAR SYSTEM

The members of the system. — A diagram of the solar system is given in Figure 211. At the centre is the sun, and, retained by its powerful attraction, a large family of bodies revolve about it. Chief of these are the planets, eight in number. Beginning with that nearest the sun, their names in order are: *Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus,* and *Neptune.* They rotate on their axes, and the orbits followed by them are all ellipses, with the sun in one focus, but in no case does the ellipse differ greatly from a circle. Around most of the planets smaller bodies known as *satellites* or *moons* revolve, much as the planets themselves move about the sun.

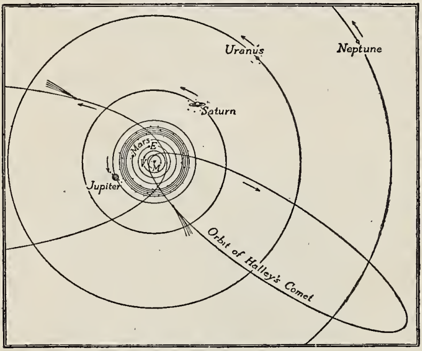


FIG. 211. — The solar system.

In the space between the orbits of Mars and Jupiter a multitude of little planets, known as *asteroids* or *planetoids,* revolve. The first of these was discovered on the first day of the last century (January 1, 1801), but now

over 600 are known to exist. They are small bodies, usually but a few miles in diameter, and too faint to be seen with the naked eye. In the sun's family we must also include *comets* and *meteors.*

The planets change their positions in the sky from year to year, but there are many other bodies to be seen which do not change their positions relative to each other. These are the *fixed stars,* and are not a part of our system.

The sun. — It is difficult to conceive the size of the sun. Its diameter is 866,000 miles, or almost 110 times that of the earth. The width of an ordinary road allowance is 66 feet. Let us take a sphere with a diameter of 60 feet, that is, 6 feet less than the width of the road, to represent the earth. Then on the same scale the sun would be represented by a sphere $1\frac{1}{4}$ miles in diameter, which is the length of the ordinary country "block" in Ontario. Or consider the following illustration: The moon pursues its course in space at the distance from us of about 240,000 miles. Now the sun is so immense that if it were a hollow ball and the earth were placed at its centre, then the moon could revolve at its present distance and still be only a little more than halfway from the centre to the circumference (see Fig. 212).

The sun's volume is 1,300,000 times that of the earth, but its density is only one-fourth as great, and hence its mass is about 332,000 times that of the earth.

The amount of light and heat emitted by the sun is simply stupendous. Our most brilliant artificial light — the electric arc — is much less brilliant than the sun. A moment's thought will make us realize that the heat received by the earth from the sun is enormous. Upon the deck of a steamer in tropical waters enough heat falls to propel it at the rate of about 10 miles an hour if the heat could be fully utilized. And yet, out of 2,000,000,000 parts emitted by the sun, the earth inter-

cepts only one! The temperature at the sun's surface is high enough to melt the most refractory substances and turn them into vapours. The spectroscope has demonstrated the presence in the sun of the vapours of iron, calcium, and many other terrestrial substances.

The parts of the sun. — The dazzling surface which we see and which radiates the sun's light is called the *photosphere.* To the naked eye (protected by a coloured glass) it appears a uniform bright disk. When seen in a small telescope, the surface looks mottled, much like rough drawing-paper.

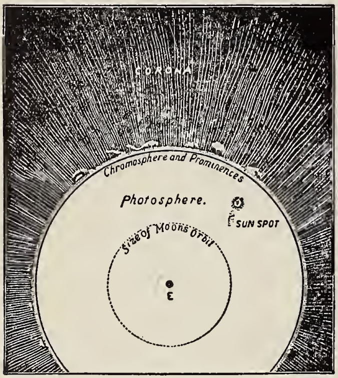


FIG. 212. — Diagram of a section of the sun through its centre.

Frequently dark places, known as *sun-spots,* are seen on the photosphere. Generally they have a dark centre, called the *umbra,* with a somewhat brighter fringe called the *penumbra.* Even the darkest portions of the sun-spot, however, are dark only by contrast. These spots are sometimes of immense size, occasionally 150,000 miles across. The largest ones can be seen with the naked eye, observations being made at sunset or through a fog or a smoky atmosphere or by the help of a coloured glass.

For the most part the spots are confined to two belts between 5° and 40° north and south of the sun's equator. If we sketch the sun's disk day after day, marking the positions of the spots on it, we find that they move across it. This indicates that the sun rotates on its axis, and

by timing the spots we find that its period is about $25\frac{1}{4}$ days.

Overlying the photosphere to a depth of 5000 to 10,000 miles is the *chromosphere.* At the time of a total eclipse, when the intense light of the photosphere is shut off, the chromosphere, as seen through a telescope, has been described as like a prairie on fire. It is composed chiefly of hydrogen, helium and calcium vapour. Projecting outward from the chromosphere are certain cloudlike forms, usually reddish in colour, known as *prominences* or *protuberances.* Sometimes these rise as high as 300,000 miles.

Beyond the chromosphere is still another envelope known as the *corona.* It can be seen only at the time of a total eclipse, and is one of the most beautiful and impressive of all natural phenomena. It is made up of filaments and rays which run outwards from the sun and are often strangely curved and intertwined. The corona sometimes extends several millions of miles from the sun's surface. The matter composing it is extremely rare. Comets have been known to sweep through it without suffering the slightest alteration in their velocity.

THE MOON

Size and distance. — The diameter of the moon is 2163 miles, and its distance from us about 240,000 miles. Its mass is $\frac{1}{81}$ that of the earth, and its density 3.4 times that of water.

By observing the position of the moon among the stars for several nights, — or, indeed, for several hours, — it will be seen to be in motion. Its *sidereal period,* that is, the time it requires to move from a star around to that star again, is about $27\frac{1}{3}$ days. Now the sun also moves among the stars in the same direction as the moon; hence the time required for the moon to pass from the sun

around to the sun again is longer than the sidereal period. It is about $29\frac{1}{2}$ days, a little less than one month. This is called its *synodic period.* The moon always presents the same face to the earth, from which we conclude that the moon rotates on its axis in $27\frac{1}{3}$ days, its sidereal period.

The moon's phases. — The moon is a cold, dark, opaque sphere, and is seen only by the sunlight reflected from its surface. It is evident that only that half of its surface which is turned towards the sun will be illuminated at once, the other half being in darkness. As the moon revolves, we see varying portions of the illuminated face, and this causes its *phases.* Suppose the moon to be in position *a* Fig. 213, that is, in the direction of the sun as seen from the earth.

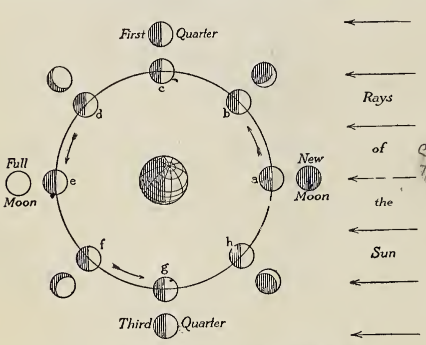


FIG. 213. — Diagram to explain the phases of the moon.

It is clear that the illuminated half is turned away from the earth, and we cannot see it at all. At this time the moon is said to be *new.* The moon moves onwards in the direction shown by the arrow, and when at the position *b*, that part of the illuminated portion which we see is shaped like a crescent. In about one week after new moon, one-quarter of the entire orbit is traversed, and the position *c* is reached. Then we see one-half of the illuminated face, and the moon is at its *first quarter* (Fig. 214). As it goes onwards, we see more and more of the illuminated portion, until at *e* we see it all, and the moon

FIG. 214.—The moon about two days before first quarter. (From a photograph taken at the Paris Observatory, France.)

is *full*. After this it appears to diminish in size. At *g* we see one-half again, and the moon is at *third quarter* (Fig. 215). At *h* it again has the crescent shape, and after $29\frac{1}{2}$ days it comes back to *a*, and we have *new moon* once more. The form assumed at *d* and *f* is said to be *gibbous*, which means "swelling." It is to be noticed that the horns of the crescent are always turned from the sun.

The surface of the moon. — Even with the naked eye one can see dark markings on the moon's surface, but with a good field-glass or a small telescope a great many wonderful details can be seen. The dark portions are known as "seas" or "oceans," though there certainly is no water in them now. The surface as a whole is extremely rough. There are several

FIG. 215.—The moon at its third quarter. (From a Paris Observatory photograph.)

mountain ranges, and almost every part of the surface is pitted with great *craters,* which resemble closely the volcanic craters on the earth's surface, but on an immensely greater scale. The greatest known terrestrial crater, the Aso San in Japan, is 7 miles across, while the lunar craters are frequently 50 or 60 miles, and in some cases over 100 miles across. There are thousands of smaller ones, some not more than half a mile in diameter (Fig. 216).

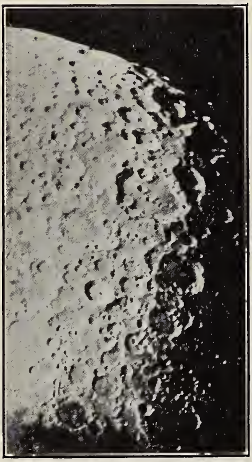


Fig. 216. — A portion of the moon showing craters. (From a photograph taken at the Dominion Astronomical Observatory, Ottawa.)

The heights of the mountains are very great, many of them being more than 15,000 feet, and some being 20,000 feet, which is more than two-thirds that of Mt. Everest, the highest peak on earth. When we remember that the earth's diameter is almost four times that of the moon, we recognize that the lunar mountains are relatively on a much grander scale than our own.

THE PLANETS

The planetary system. — The planets are dark globes shining only by reflected sunlight, revolving around the sun in orbits nearly circular, moving all in the same direction and nearly in the same plane.

Leaving out the asteroids, the eight *principal* planets may conveniently be divided into two groups: 1. The inner or terrestrial planets, — *Mercury, Venus, Earth, Mars.* 2. The outer or major planets, — *Jupiter, Saturn, Uranus, Neptune.*

There are many points of contrast between the two groups. The inner planets are much nearer the sun, their distances ranging from 36 to 142 millions of miles, while the distances of the outer planets range from 480 to 2790 millions of miles. In the wide gap between the two groups the asteroids are found.

The inner planets are much smaller than the outer. Mercury is the smallest, with a diameter of 3030 miles; the earth the greatest, with a diameter of 7918 miles. Of the outer planets Uranus is the smallest, with a diameter of 32,000 miles, while the mighty Jupiter has a mean diameter of 86,000 miles (see Fig. 217).

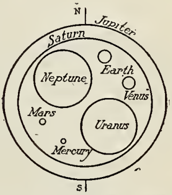


FIG. 217. — Diagram showing the relative sizes of the planets. Notice that Jupiter and Saturn are much flattened at the poles.

Again, there is a striking difference in the densities of the members of the two groups. The densities of the inner planets, taken in order, are 4.7, 4.9, 5.5, 3.9, while those of the outer planets are 1.3, 0.7, 1.2, 1.1.

Mercury. — The diameter of this planet is 3030 miles, or about $1\frac{1}{2}$ times that of the moon. Its mass is not accurately known, but its density is probably about 4.7 times that of water. It revolves about the sun in 88 days, and, it is believed, always presents the same face to the sun, in which case it rotates on its axis in 88 days also. On the sunless side there is perpetual night and intense cold, while the opposite side is continuously exposed to a blaze of sunbeams seven times as powerful as they are on reaching the earth.

Venus. — Venus is by far the brightest and most conspicuous of the planets. It is a twin sister of the earth in size, density, and general constitution. Its distance from the sun is 67,000,000 miles, and so it receives much more heat and light than the earth does.

The diameter of Venus is 7700 miles, its density is 4.9 times that of water, and it revolves about the sun in 225 days. Like Mercury, it is believed always to present the same face to the sun.

Mars. — The orbit of Mars is beyond that of the earth, its mean distance being 141½ millions of miles. When it is nearest to the earth, its brightness and ruddy colour render it a striking object; and as it appears to have little atmosphere, many details of its surface can be observed with a good telescope (Fig. 218). It has greenish markings on a reddish background, and by watching these for a few hours, it is readily seen that the planet rotates on its axis. What looks like a great snow-cap appears at the poles during the Martian winter and disappears in the summer. Some faint straight lines have also been recognized. These are believed by some to be real artificial canals for the conveyance of water.

Fig. 218. — Mars, from a drawing made at the Lowell Observatory. The fine lines at the bottom are the so-called "double canals." In the telescope they are very faint, not nearly so clear as in this picture.

Mars revolves about the sun in 687 days and rotates on its axis in 24 h. 37 m. Its diameter is 4230 miles. It has two small moons, whose periods of revolution are 7 h. 39 m. and 30 h. 17 m., respectively. Thus the former revolves about Mars three times while the planet is rotating on its axis once.

Jupiter. — This planet, when brightest, is a striking feature of the heavens all night long.

Its period of revolution is 11.86 years, while it rotates

on its axis in the short space of 9 h. 55 m. Its equatorial diameter is nearly 90,000 miles, and its polar diameter 84,200 miles. Even in a small telescope the flattening at the poles can be seen. This flattening is due to the planet's rapid rotation. Its density is only 1.3, but on account of its enormous size its mass exceeds that of all the other planets combined.

It is generally believed that Jupiter is still very hot and far from the cool, solid state of the earth. Jupiter is known to have eight moons, four of which are visible in a field glass, but the other four only in the greatest telescopes.

On the surface of the planet distinct coloured bands parallel to the equator can be seen, and changes in them show that what we see is a cloudy envelope.

Saturn. — The equatorial diameter of this planet is about 75,000 miles, the polar diameter 67,400 miles.

Fig. 219. — Saturn, from a drawing by Keeler, made at the Lick Observatory.

Its density is only 0.7 (water = 1), but its mass, nevertheless, is 95 times that of the earth. It rotates in 10 h. 14 m. Saturn is known to have ten satellites, the ninth of which revolves about the planet in the opposite direction to the others. In addition, Saturn has a wonderful ring 173,000 miles across and less than 50 miles in thickness (Fig. 219). The physical condition of the planet probably

resembles that of Jupiter. In a telescope Saturn is a beautiful spectacle.

Uranus and Neptune. — The former was discovered in 1781 and the latter in 1846. They are so far away that little is known of their periods of rotation or of the nature of their surfaces. Uranus has four satellites and Neptune one, and, unlike all the other members of the solar system, they revolve in planes greatly inclined to the plane of the ecliptic.

ECLIPSES

Cause of eclipses. — If the plane of the moon's orbit coincided with that of the ecliptic (that is, if the centres of the sun, earth, and moon were always in the same plane),

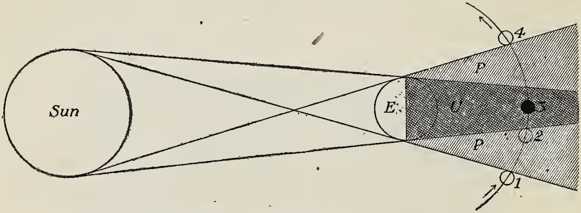


Fig. 220. — Showing how an eclipse of the moon is produced.

every time the moon revolved about the earth it would plunge into the earth's shadow and be eclipsed. When on the opposite side of its orbit it would come between the sun and the earth, and we would have an eclipse of the sun.

In reality the moon's orbit is inclined 5° 9′ to the ecliptic plane, and the moon's path in the sky cuts the ecliptic in two points, called its *nodes*, in opposite parts of the heavens. When the sun, in its annual motion along the ecliptic, comes to one of these nodes, we have eclipses.

Eclipse of the moon. — In Figure 220 is shown how an

eclipse of the moon is produced. The moon is shown in four positions. In the first it has just come to the partial shadow or *penumbra;* in the second it has just reached the true *shadow;* in the third it is entirely within the shadow; and in the fourth it has just escaped from the penumbra. When it is entirely within the shadow, the eclipse is total.

Eclipse of the sun. — The way in which an eclipse of the sun is produced is illustrated in Figure 221. It will

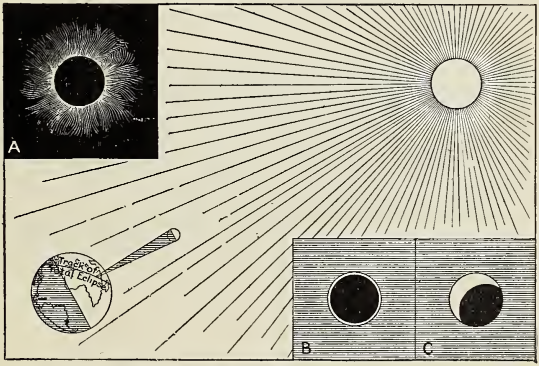


FIG. 221. — Eclipse of the sun — *A*, total; *B*, annular; *C*, partial.

be seen that the shadow cast by the moon is conical, and the part which touches the earth is near the apex. For this reason it covers only a small portion of the earth's surface, and so, if we wish to see the sun totally eclipsed, we must travel to that limited portion of the earth's surface. On account of the motion of the moon onwards in its orbit, and the rotation of the earth on its axis, the shadow travels across the earth's surface, tracing out the *track of the eclipse.* This track is never more than 160 miles wide

Now the orbit of the moon is an ellipse, with the earth in one focus, and hence the moon is farther from us at some times than at others. Indeed, its distance varies from 222,000 to 253,000 miles, and on account of this it sometimes happens that the shadow cone falls short of the earth. In this case the sun is not entirely hidden, but a narrow ring around the dark image of the moon is seen. This is an *annular* eclipse (*B*, Fig. 221).

A person may be a considerable distance on either side of the eclipse track and still see a portion of the sun obscured. To him the sun is *partially eclipsed* (*C*, Fig. 221).

COMETS AND METEORS

Comets. — Until comparatively recent times comets were thought to be simply phenomena of the earth's atmosphere. Newton, however, demonstrated that they move about the sun, and Halley showed that the comet which bears his name travels in an ellipse, returning every 75 or 76 years.

Instead of moving as the planets do (namely, in ellipses which are nearly circles and almost in the same plane), comets travel in parabolas or very long ellipses, the planes of which are inclined to the ecliptic plane at all angles. Those travelling in parabolas come from the depths of space, sweep about the sun, and then move off, never to return. If the path, however, is an ellipse, the comet will return, whether after few or many years.

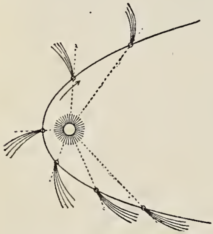


FIG. 222.—Showing how the comet's tail points as it moves about the sun.

On an average five comets are discovered each year, but most of them are faint, hazy patches, not visible without telescopic aid. Yet some of these, when they arrive in

the neighbourhood of the sun, develop wonderful tails. The great comet of 1843 had a tail 198 millions of miles long, the longest on record. The tail always points away from the sun (Fig. 222). Observation seems to show that the tail is composed of finely divided matter continuously emitted from the head of the comet, and sunlight falling on it drives it away from the sun.

At the present time comets are studied almost entirely by photography. In Figure 223 is a photograph of Halley's Comet. The orbit of this comet is an ellipse,

FIG. 223. — Photograph of Halley's Comet taken at the Dominion Astronomical Observatory, Ottawa, May 27, 1910. Exposure, 40 minutes.

the aphelion of which is beyond the orbit of Neptune, while the perihelion is within the orbit of Venus (see Fig. 211), about 54 millions of miles from the sun.

Meteors. — On almost any clear, moonless night, by watching a few minutes, one may see some of the familiar "shooting-stars." Bright, star-like points dart across the sky and quickly disappear. Sometimes, however, a much more brilliant meteor is seen. Like a great ball of fire it ploughs through the air, leaving a trail behind which may persist for minutes. On some occasions the flight of the body is accompanied by loud explosions and a continuous roar like that of a passing railway train. Numbers of these bodies have actually been seen to strike the earth,

and have been recovered from being buried a foot or two deep in the soil.

Such bodies are called *meteorites*. Most of those actually seen to fall are of a stony nature, but about 3 or 4 per cent are of nearly pure iron, more or less alloyed with nickel. Careful chemical analysis has revealed the presence in these bodies of about twenty-five of our terrestrial elements, but no new ones. However, there are found in the meteorites certain crystalline formations which are not met with anywhere else. These peculiarities enable us to recognize as of meteoric origin certain bodies found in the earth, though no evidence is forthcoming as to the time of their fall from the sky. A large number of meteoric irons have been recovered, often being turned up by the plough. A beautiful specimen is in possession of Victoria College, Toronto (Fig. 224). Its weight is 386 pounds, and its composition is: iron, 91.3; nickel, 8.8, with a little cobalt. It was found near Iron Creek, a tributary of the Battle River, about 150 miles south of Victoria, on the North Saskatchewan River. It was greatly venerated by the Indians.

Fig. 224. — A meteorite in Victoria College, Toronto.

The largest known meteorite is in the American Museum of Natural History in New York. It is a huge mass of meteoric iron weighing $37\frac{1}{2}$ tons, and was brought from Greenland by Peary, the arctic explorer.

At about 8 o'clock on the evening of August 13, 1904, two meteorites fell in the neighbourhood of the village of

Shelburne, Grey County, Ontario. The brilliant flash was seen over 60 miles, and the accompanying sound heard over 35 miles away. Two stones were recovered, one of which weighed $27\frac{3}{4}$ pounds, the other $12\frac{1}{2}$ pounds, the distance between the points of fall being about three-quarters of a mile. The way in which they fitted together is shown in Figure 225. The stones were composed of the following minerals: nickel-iron, 8.5; troilite, 4.5; chromite, 0.8; schreibersite, 0.4; olivine, 45.0; enstatite, 27.8; aluminium-silicate, 13.0 per cent. The density was 3.5 times that of water.

Fig. 225. — The two meteorites which fell near Shelburne. The photograph shows how the stones were originally united.

The incandescence of the body is produced by its rapid flight through the atmosphere. By simultaneous measurements made by two observers stationed several miles apart, it has been shown that the paths of these bodies are at altitudes ranging from 50 to 100 miles, and that they travel at speeds from 10 to 40 miles per second. The heat generated by friction against the atmosphere is confined almost entirely to the surface layer, which is fused and blackened, much as though covered with black varnish. The surface of a meteorite may be white-hot, while the interior is intensely cold.

The number of shooting-stars is very great. It has been computed that millions enter the atmosphere every day. Ordinarily the bodies are small, perhaps like dust

or fine shot, and being consumed in the upper regions of the atmosphere, they slowly settle down to the earth's surface as fine powder. If the body is too large to be consumed in its passage through the atmosphere, it falls to the earth. It would seem, then, that distributed throughout space there are portions of matter varying from grains to tons in weight moving about the sun. When any of these enter the earth's atmosphere their speed is checked, and the earth's attraction draws them inwards.

ORIGIN OF THE SOLAR SYSTEM

Development in the solar system. — In our study of nature there is nothing which impresses the mind so much as the evidence of a process of development in everything we see. In the case of animals and plants we recognize a birth, a period of growth, and then a time of decay and dissolution. No object can be considered *permanent*. Everything is subject to a power continually seeking to change it.

The solar system is subject to the same laws of nature, and must have undergone a process of development or evolution. At some time long past it was radically different from what it is now, and in the ages yet to come it will assume a form quite different from that which it bears to-day. What the original form of our solar system was has long been a favourite subject for speculation.

The nebular hypothesis of Laplace. — Let us imagine ourselves to be far up in space towards the north star and looking down upon the various bodies of the solar system. We would observe the following wonderful concords in their motions. The motions of the planets are in the same direction and very nearly in the same plane; the motions of the satellites (with few exceptions) are in the same direction as those of the planets; the motions of rotation

of the different bodies and also of the sun are (with few exceptions) in the same direction as the orbital motions, and in planes very little inclined to each other; the eccentricities of the orbits of the planets and satellites are very small, that is, the paths are nearly circular. A little thought on these extraordinary coincidences must suggest that they have not come about through simple chance, but are rather due to some single original cause, or are the working out of a great design.

A consideration of the solar system as known at his time led Laplace, a very distinguished French mathematical astronomer, to propose in 1796 his *nebular hypothesis*. According to it, the matter now constituting the various bodies of the solar system was at one time in the form of an intensely hot, nebulous gas, which extended beyond the orbits of all the planets, and which had a motion of rotation approximately parallel to the plane of the ecliptic. Under the action of its own gravitation the nebula assumed the globular form, and as it gave out its heat it continually contracted. As it became smaller, its speed of rotation increased, and the nebula became flattened at the poles, bulging out at the equator. Finally the centrifugal force at the equator was equal to the attraction, and a ring of nebulous matter was left behind. The central mass still continued to contract, becoming more flattened, and successive rings were left behind. Each ring then contracted, condensed and formed a planet. The planets thus formed continued to revolve about the central mass, and by rotation on their axes left off rings which condensed into a system of satellites.

The hypothesis as presented by Laplace completely explained all the facts as known at his time, but some discoveries made since then cannot be easily fitted into the theory. The ninth satellite of Saturn (discovered in 1898) revolves in the retrograde direction, and the

satellites of Uranus and Neptune revolve in planes far out of the ecliptic plane and in the retrograde direction. Also one of the moons of Mars revolves about the planet in less than one-third of the time taken by the planet to rotate on its axis. If the development has been in the manner outlined by Laplace, this result would be entirely unexpected.

An attempt has been made to reconcile with this theory the fact that Mars rotates more slowly than its moon revolves, by means of what is known as *tidal friction.* On pages 228–233 an explanation is given of how the attractions of the sun and moon heap up the waters of the ocean and produce tides. Very delicate measurements have shown that even the solid earth slightly changes its shape under the same attractive forces. It is supposed that early in its history, when Mars was a much larger sphere of plastic material, the sun raised great tides upon it. As the raised portions would continuously point approximately towards the sun, they would act as a brake upon the planet, reducing its speed of rotation, until at last it became longer than the period of revolution of the satellite. But there are other facts, also, which cannot easily be explained by the Laplacian nebular theory. However there is not space here to discuss them. It should be stated that Kant, a famous German philosopher, in 1755 proposed a nebular theory somewhat similar to Laplace's, but not so fully worked out in detail.

The planetesimal hypothesis. — Quite recently another theory has been proposed. It is sometimes known as the *planetesimal* (that is, "little planet") hypothesis, sometimes as the *spiral nebular* hypothesis. By far the greatest number of the nebulæ in the sky have a spiral form (Fig. 226), and it is supposed that our system was developed from one of this kind. But in the new theory the substance of the nebula is taken to be not highly

heated gas in a very rarefied state, but rather small moving particles of matter attracting each other, and all circulating about the central portion like innumerable little planets.

In the arms of the spiral shown in Figure 226 there are seen various condensations. These are supposed to be the nuclei of the planets of a system, and as some of them are larger than others, the planets have different sizes. As they revolve about the central mass, which contracts to form the *sun* of the system, they attract to themselves smaller masses in their neighbourhood, and thus they grow in size. Under the attraction of gravitation they are drawn into globes, and the compression generates heat and drives out the volatile substances to form the atmosphere and the oceans.

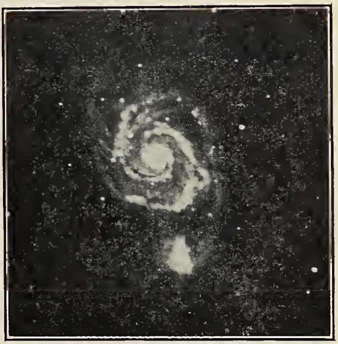


FIG. 226. — A spiral nebula in the constellation "The Hunting Dogs." (From a Lick Observatory photograph.)

The planetesimal hypothesis finds favour with geologists. It allows a longer time since the earth became solid, and a greater amount of shrinkage to provide for mountain-building.

It must not be forgotten, however, that these are only hypotheses, shrewd guesses. We are certain that the solar system has been developed from some simple form quite different from what it has now, but just the steps followed in the process of transition we may never know.

CHAPTER XIX

THE UNIVERSE OF STARS

The fixed stars. — The light which we receive from the planets and their satellites is only reflected sunlight, but far beyond our system are hosts of bright bodies shining by their own light. These are the *fixed stars*. They are suns, and the spectroscope tells us that they are composed largely of the same substances as our sun, though they differ somewhat in their physical conditions. They are at different stages in the process of their development. Some of them are hotter and more gaseous than our sun, while others are cooler, and hardly shine at all. The former are pearly white, the latter dull red.

These stars are said to be *fixed* because to ordinary observation they have always the same relative positions; but the measurements of modern astronomy are so refined that we have been able to prove that most of them are in motion. But the change of position is so small that if the ancient Chaldæan astronomers (2000 B.C.) could again view the sky, they would hardly be able to detect any change in the relative positions of the stars.

The number of stars which can be seen with the naked eye is only about 5000, and less than half of these can be seen at any one time. But an ordinary opera-glass brings out at least 100,000, and our largest telescopes exhibit probably over 100,000,000.

The distances of the stars from us are simply inconceivable. Light travels at the enormous speed of 186,000 miles per second. It can encircle the earth in the wink

of an eye, and can come from the sun to us in $8\frac{1}{3}$ minutes; and yet for it to travel from the nearest of the fixed stars to us requires $4\frac{1}{3}$ years. To come from the Pole Star takes 44 years, while some of the stars are so far away that 1000 years are required for the transmission of their light to us.

With respect to their brightness the stars are classified in *magnitudes.* Stars of the first magnitude are two and one-half times as bright as those of the second, which again are two and a half times as bright as the third magnitude stars, and so on. Stars of the sixth magnitude are just visible to the naked eye on a dark night. How far down the magnitudes go no one can say, since with every increase of telescopic power fainter stars have been revealed. The brightness of some stars, however, is not constant. In some cases it varies according to known laws, but in others it is very irregular. Such are known as *variable stars.* There are also *double stars,* which often consist of two bodies (one of them sometimes dark) revolving about their common centre of gravity.

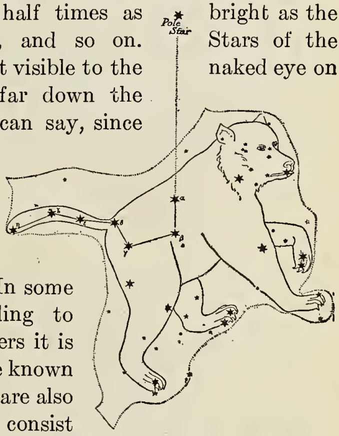


Fig. 227. — The constellation *Great Bear.*

The constellations. — From very ancient times the stars have been grouped in *constellations,* the names of which are largely drawn from Greek and Roman mythology. It usually, however, requires a lively imagination to see in the constellation any resemblance to the object whose name it bears.

The most conspicuous northern constellation is known

as *Ursa Major* or the *Great Bear* (Fig. 227). In our latitude it never sinks below the horizon. The most striking part of the constellation is the group of seven stars forming the "Big Dipper." It is usual to name the prominent stars of a constellation by the letters of the Greek alphabet, and the seven forming the dipper are: α (Alpha), β (Beta), γ (Gamma), δ (Delta), ϵ (Epsilon), ζ (Zeta), η (Eta). The two outer stars in the "bowl," namely, α and β, are called the "pointers," since a straight line joining them, if extended about five times the distance between them, will end close to the Pole Star. Any one who can identify the "Dipper," and has a star-map, can readily locate the other constellations.

FIG. 228.—*Orion*, the finest constellation.

Another fine constellation is *Orī'on*, the glory of the winter sky (Fig. 228). It is just at the celestial equator. In the old mythology Orion was a famous giant and hunter. The two brightest stars, which are both of the first magnitude, are known as α and β, though they are also known by the names Betelgeuse and Rigel.[1] The former is of a ruddy colour, the latter pearly white. Three second-magnitude stars, just one degree apart, form the "belt" of the giant. By continuing the line of the "belt" to the left and downwards (*i.e.* in the south-east direction), we reach *Sirius*, the "Dog Star," which is the brightest of all the fixed stars. In the "sword" hanging from the "belt" is the *Great Nebula* (Fig. 230), which can be detected by an opera-glass.

In *Taurus* ("The Bull"), a constellation next to Orion,

[1] Pronounced *Bet'el-gūz, Rī'gel* or *Rī'jel.*

is a very famous little group of stars known as the *Pleï′-ades*. They are often referred to in literature. Tennyson aptly describes them as "a swarm of fire-flies tangled in a silver braid."

Fig. 229. — Cluster of stars in the constellation *Hercules*. (Lick Observatory Photograph.)

In various parts of the sky other small groups are to be found which the eye cannot resolve, but which the telescope shows to be magnificent *clusters*. In one cluster, in the constellation *Hercules*, there are several thousand stars within a space one-fourth of the diameter of the moon (Fig. 229).

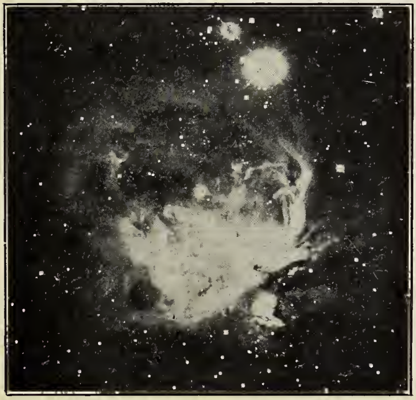


Fig. 230. — The Great Nebula in *Orion*. (Yerkes Observatory photograph.)

The nebulæ. — But perhaps the most wonderful objects of all are the faint, cloud-like bodies seen against a dark sky, called *neb-*

ulæ. There are thousands of them, but only a few can be well *seen* in the telescope. Those in Orion and in Andromeda can be easily discerned with an opera-glass, and the unique "Ring" nebula in Lyra (Fig. 231) can be seen with a small telescope; but as a rule the details of these delicate, filmy objects are best revealed by photography.

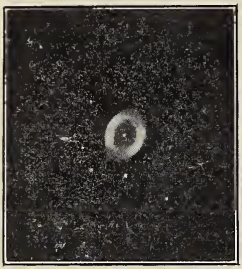


FIG. 231. — The Ring Nebula. (Lick Observatory photograph.)

On giving an exposure, ordinarily of three or four hours, with a suitably designed telescope, some extraordinary pictures have been obtained. The Great Nebula in Orion (Fig. 230) covers an area greater than that of the moon, but it has no definite shape.

Many observations have led to the belief that the nebulæ are the raw material from which the stars and their systems are being formed. The nebula condenses and forms the sparkling white stars, and in process of time these change to yellow, then to red, and finally to "dark" stars. In the sky there are untold millions of dark bodies as well as of bright ones, and the spectroscope indicates all are composed of the same kind of matter. In this we see a wonderful unity in the universe.

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Date Due
